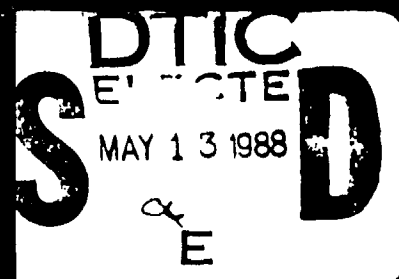# THE VARIABILITY OF GERMAN WINTER TEMPERATURE IN RELATION TO HUMAN PERFORMANCE AND ITS IMPLICATIONS FOR TACTICAL MILITARY OPERATIONS

1988

MARK ALAN YESHNIK

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

3. [illegible stamp]

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
The Pennsylvania State U.

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS (City, State, and ZIP Code)
University Park , PA
16802

7b. ADDRESS (City, State, and ZIP Code)

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
HQDA, MILPERCEN (DAPC-OPA

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code)
-E), 200 Stovall Street
Alexandria, VA 22332

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
The Variability of German Winter Temperature in Relation to Human
Performance and its Implications for Tactical Military Operations

12. PERSONAL AUTHOR(S)
CPT Mark A. Yeshnik

13a. TYPE OF REPORT Masters Thesis	**13b. TIME COVERED** FROM _____ TO _____	**14. DATE OF REPORT (Year, Month, Day)** Final Report May 1988	**15. PAGE COUNT** 128

16. SUPPLEMENTARY NOTATION

Approved for public release; distribution unlimited

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Thesis submitted to the Pennsylvania State
University in partial fulfillment for the degree
of Masters of Science

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
Germany's climate and geographical location have historically played an
important role in the outcome of many military campaigns. Modern climatic
conditions will likewise effect exposed military personnel. Exposed soldiers
respond physiologically and behaviorally to extreme cold depending on their
energy stores, sex, build, race, and metabolic activity. These responses
are reviewed in terms of the energy balance of the human body, the factors
which limit thermogenesis, and the various means of measuring and assessing
the impact of temperature. A value of 0 C, the temperature at which human
tissue freezes, is used as a threshold at which the adverse effects of cold
become significant to military operations to include decreased resistance
to infection and levels of performance. German winter temperature can be
characterized by large intraseasonal and interannual variability and a
general lack of persistence of climatic elements. As part of this variability

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED   ☐ SAME AS RPT.   ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION

22a. NAME OF RESPONSIBLE INDIVIDUAL

22b. TELEPHONE (Include Area Code)

22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

Theses

important to military operations, the region is prone to sudden and sometimes prolonged outbreaks of cold air. These extreme periods of cold are associated with northerly, meridional flows indicating the importance of air trajectories in the climate of this region. Topography reduces the impact of these air flows from north to south. The North Atlantic Oscillation Index, a measure of the pressure difference and therefore strength and trajectory across the North Atlantic and adjacent sectors, explains much of the variance in German winter temperatures. The relationship between meridional flows and low temperatures has important implications for military tactical operations, in that it decreases performance levels and resistance to infection of the soldier in the field.

The Variability of German Winter Temperature in Relation to
Human Performance and its Implications for Tactical Military
Operations

Captain Mark A. Yeshnik
HQDA, MILPERCEN (DAPC-OPA-E)
200 Stovall Street
Alexandria, VA 22332

May 1988

Distribution Statement A

The Pennsylvania State University

The Graduate School

Department of Geography

THE VARIABILITY OF GERMAN WINTER TEMPERATURE IN RELATION

TO HUMAN PERFORMANCE AND ITS IMPLICATIONS

FOR TACTICAL MILITARY OPERATIONS

A Thesis in

Geography

by

Mark Alan Yeshnik

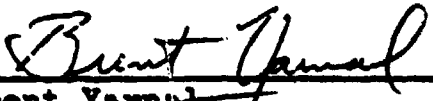Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

May 1988

We approve the thesis of Mark Alan Yeshnik.

Date of Signature

Brent Yarnal
Assistant Professor of Geography
Thesis Advisor

7 March 1988

Robert G. Crane
Assistant Professor of Geography

3 / 7 / 88

C. Gregory Knight
Professor of Geography
Head of the Department of
    Geography

3/7/80

ABSTRACT

Germany's climate and geographic location have historically played an important role in the outcome of many military campaigns. Modern climatic conditions will likewise effect exposed military personnel. Exposed soldiers respond physiologically and behaviorally to extreme cold depending on their energy stores, sex, build, race and metabolic activity. These responses are reviewed in terms of the energy balance of a human body, the factors which limit thermogenesis and the various means of measuring and assessing the impact of temperature. A value of 0° C, the temperature at which human tissue freezes, is used as the threshold at which the adverse effects of cold become significant to military operations to include decreased resistance to infection and levels of performance.

German winter temperature can be characterized by large intraseasonal and interannual variability and a general lack of persistence of climatic elements. As the part of this variability important to military operations, the region is prone to sudden and sometimes prolonged outbreaks of cold air. These extreme periods of cold are associated with northerly, meridional flows indicating the importance of air trajectories in the climate of this region. Topography reduces the impact of these air flows from north to south. The North Atlantic Oscillation index, a measure of the pressure difference, and therefore strength and

trajectory across the North Atlantic and adjacent sectors, explains much of the variance in German winter temperatures. The relationship between meridional flows and low temperatures has important implications for military tactical operations, in that it decreases performance levels and resistance to infection of the soldier in the field.

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Chapter 1

INTRODUCTION

In the winter of 1812, Napoleon Bonapart led his Grand Armèe across the frontier to do battle with the Russian forces. His Russian campaign was one of the greatest military enterprises in human history. More than a million combatants stood in opposing lines. Napoleon´s army was the largest and best trained of its time. Morale was high and the confidence of his men was unshakable. In mid-October, the weather broke, and so did the morale of Napoleon´s Grand Armèe. Of the 680,000 men which followed Napoleon into Russia, 340,000, or one-half of the total number, lost their lives. Surprisingly, more than two times the number of men lost their lives due to hunger, exhaustion, cold, or disease, than to actual death in battle (Bodart, 1916). Who was the real enemy, the Russian Army, or the Russian winter?

During the winter of 1941, another great army, Hitler´s German Army, was conducting Operation Barbarossa, the invasion of Russia. Once again, the weather broke, and the campaign was brought to a standstill. First mud, then cold plagued the German army. In early December, Hitler´s frostbitten soldiers had run out of steam. Operation Barbarossa cost the Germans 750,000 casualties. Of those, only 200,000 were actually killed in battle; the rest died

from the direct or indirect effects of the bitter weather
(Keegan, 1976).

History has shown that one should not underestimate
the importance of weather and climate in the outcome of
military events. As demonstrated above, some of the
greatest armies of all time were not defeated by other
armies, but by the effects of weather. The knowledge of how
climate and weather effect tactical military operations
must be expanded.

Some may argue that modern technology has provided
better equipment to allow soldiers to withstand the effects
of climate better than in the past. In some respects this
is true. Modern equipment is superior to what was carried
into combat in the past. However, in some ways, modern
warfare is not so different as to warrant such a
generalization. Even today, the infantry rifle platoons and
squads are the cutting edge of the division. The rest of
the division, with all its helicopters, artillery,
logistics, communications, and combat service support
exists for only one reason: to assist, support, provide
mobility for, and otherwise multiply the effectiveness of
these rifle squads and platoons (CGSC, 1975). Infantrymen
remain the most powerful and influential force on the
modern battlefield (English, 1984). The infantryman of
today, like his predecessor, is at home on the terrain. He
lives, operates, and fights exposed to the elements. He is

not familiar with campfires, tents, beds, or hot meals. He sleeps in his "fox hole" and eats cold rations, when he can find time. An infantryman moves at night, which affords him the best cover and security. He understands that the best time to attack is during a rainstorm, and his most critical time in defense is just prior to sunrise. Most of all, he walks. He walks long distances with heavy loads. Sometimes he wonders what it would be like to be warm again, or dry, or clean. Technology has come a long way in providing better equipment for the soldier. However, he still remains today, as in the past, at the mercy of the elements.

Technology has placed an added burden on today's soldier. He is required to know more and do more than his predecessor. The equipment for which he is responsible is complex, requires special maintenance, and a high level of training and expertise to operate. In poor weather conditions, he still must operate and maintain his equipment. The vigilance required on today's battlefield is, therefore, far greater than what was required in the past. To conclude that the modern infantryman is less susceptible to the effects of weather and climate is a misconception. Weather and climate play as critical a role today as they have in the past.

The Army is not indifferent to the role which climate and weather play during operations. Current Army doctrine addresses possible impacts of weather and climate during

its standardized operational planning procedures.
Intelligence Preparation of the Battlefield (IPB) is a
systematic approach to analyzing the enemy, weather, and
terrain in a specific geographical area. It is based on the
graphic portrayal of information and is dynamic, changing
with the immediate situation on the battlefield. The
weather analysis section of IPB can be described by the
following steps:

(1) Development of a climatic data base consisting of
at least five years of data.

(2) Development of a weather factor analysis matrix
which isolates those weather factors whose effects are
significant for specific combat operations.

(3) Development of weather factor overlays to convert
climatic data into graphic displays. These overlays can
include hydrology, fog, cloud cover, and precipitation.

(4) Determining the actual impact of the weather on
the terrain and operations. (SupplementR 66000, 1983)

The entire process was designed to serve the commander by
providing him an understanding of the operational and
tactical considerations of the physical environment.

It has been previously noted that weather has
historically played a vital role in operations, and that
the modern infantryman is just as susceptible to the

elements, if not more so, than his predecessor. The next logical step is to determine those geographical areas in which knowledge of climatic conditions would be advantageous for the accomplishment of critical missions.

FM 100-5 (1986) states the overall mission of the Army is to deter war. The Army supports this mission by providing combat-ready units which are charged with executing the military policies of this country and waging war should deterrence fail. The United States is part of the North Atlantic Treaty Organization (NATO) which was formed during World War II. This alliance has become the center of American foreign policy since its inception. Since Army doctrine is based on the support of foreign policy and national security objectives, it is not surprising that the doctrine of the Army revolves around the support of NATO in times of war, and, consequently, armed conflict on the battlefields of Europe.

As a gesture of our commitment to this treaty, the Army deploys units every year to Europe to participate in an exercise called Return of Forces, Germany (REFORGER). Germany plays a critical role in the overall defense of NATO. Two major avenues of approach into western Europe pass through Germany: the northern corridor, which is most closely associated with the famous Van Schliefen plan of World War 1; and the southern corridor, which runs through the Fulda gap. Germany represents NATO's front-line

defense. Militarily, historically, socially, and politically it is a key area in the defense of Europe. What occurs in this relatively small geographical area will ultimately determine the outcome of at least the first stage of any battle fought in western Europe. Given this fact and the historical impact of temperature on military operations, Germany, therefore, becomes a critical area in which the effects of weather and climatic variation on tactical military operations should be investigated.

1.1 Climate Impact Assessment

One of the most important paradigms for investigating the effects of climate on man and his activities is that of climate impact assessment (Kates et al., 1985). This is a relatively new field which has taken on added importance with increasing population pressures and decreasing conventional energy resources. The various methods which have been devised to study the interaction between climate and man can be divided into two major categories: impact models and interaction models. One of the most comprehensive models to date is an expanded impact model by Kates (1985; Fig. 1-1). The remainder of this subsection is based on Kates' (1985) work.

The expanded impact model contains four sets of elements.
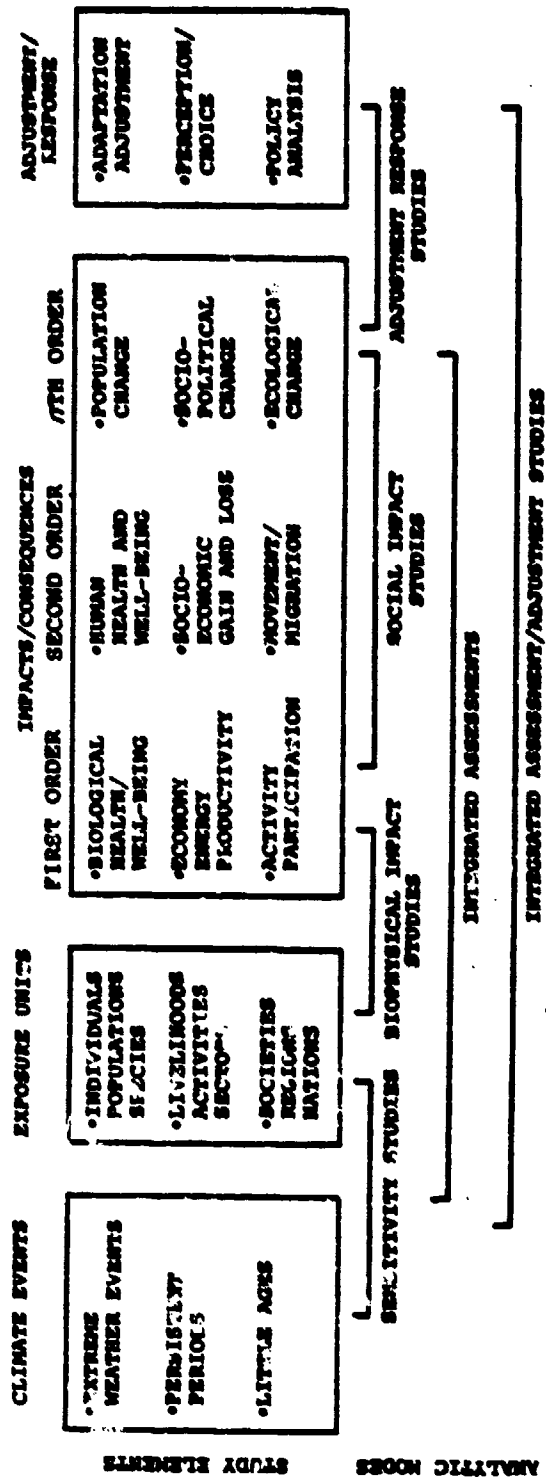
Figure 1-1. Climate impact study (Kates, 1985).

(1) <u>Climate events</u> can be extreme weather events, persistent periods, or "little ages."

(2) <u>Exposure units</u> are socially grouped (individuals, population, or species), sectorally divided (livelihoods, activities, economic sectors), or areally defined (society, regions, or nations).

(3) <u>Impacts and consequences</u> are ordered, with primary impacts on biological systems, productivity, and activities, and secondary impacts propagating through the economy, society, or the ecosystem.

(4) <u>Adjustment responses</u> are adaptive-adjustment mechanisms to prevent, reduce, or mitigate the climate impact.

Each of these sets of elements is linked by an analytic mode which provides a means of studying the connection between the sets.

Sensitivity studies link the climatic element to the exposure unit. These studies attempt to identify climate-sensitive groups, activities, and areas. Some of the research which is associated with this analytic mode includes sector sensitivity analyses, sector resiliency analyses, and climate resource sector linkage.

Biophysical impact studies link the exposure unit with the first order (primary) sector impacts. These studies

primarily concentrate on biological and physical productivity. Research in this area covers such topics as climate and sectoral models, case study research, and pathways and linkages within the social system.

Social impact assessments examine how the biophysical impacts are propagated into and through the socio-economical and political systems. Research in this area focuses on human populations, and includes level and distribution of effects, indicators of societal impacts, trends, vulnerability studies, and case studies of past societies and marginal areas.

Adjustment response studies is yet another research mode. They link impacts with responsive behavior. Research in this area is concerned with the mechanisms of adjustment, the role of information availability and efficiency, as well as perceptions.

Integrated assessments must include at least three of the above analytical modes: sensitivity studies, biophysical impact studies, and social impact studies. This type of research focuses on the integrative constraints and incentives of various strategies and can provide large-scale connections between strategies and resource problems.

Formal climate impact assessment is complex and requires the interrelated efforts of many disciplines. A group of researchers with a large budget and ample access to wide amounts of expertise would take months to years to

compile such an assessment. Although this is well beyond
the scope of this study, there are certain aspects of
climate impact assessment which bear particular relevance
and importance to tactical military operations.

1.2 The Impact of Cold on Military Operations

One aspect of climate that affects military operations
is that of severe cold on exposed troops. From Napoleon, to
Hitler, to today, this critical factor has taken its toll
during war.

In general, temperatures can have a direct effect on
the terrain, on equipment, and on individuals. Effects of
low temperatures on terrain during the winter season are
minimal. In fact, very cold periods will actually aid in
trafficability, and from this standpoint can be considered
a positive effect. Temperature impacts on equipment also
tend to be minimal. The Army's design and acquisition
process establishes very strict criteria for the
operational requirements of its equipment. Equipment is
designed so that it can operate effectively within extreme
ranges of temperature and precipitation. Extreme low
temperatures outside this range are unlikely. Therefore,
impacts of temperature on equipment are minimized in the
research and design stage of the acquisition process. In
addition, temperature impacts on equipment tend to be
second-order and logistical in nature. Under extreme

temperature conditions, equipment normally fails from an inability of the logistical system or the operator to properly maintain the equipment, rather than from the direct effect of temperature.

The impact of abnormally low temperature on individuals can have a dramatic impact on tactical operations. One only needs to refer back to Operation Barbarossa to appreciate the possible magnitude of these impacts. It is this impact of cold on individuals which is of utmost concern for tactical operations. Although a full climate impact assessment of the possible effects of temperature on soldiers is beyond the scope of this study, there are certain basic concepts which warrant further consideration. In short, individuals may respond to temperature changes either through physiological or behavioral adjustments. Physiological adjustments, or thermoregulation, result when an individual's mean body temperature deviates from normal beyond a certain threshold. Behavioral adjustments can vary from changes in posture to clothing. By understanding these various responses, and the factors which elicits those responses, it may be possible to minimize the adverse impact of extreme low temperature on individual soldiers.

1.3 Study Objectives and Outline

The primary objective of this thesis is to study the climatic record of East and West Germany in order to identify abnormally cold winters which would impact on military operations. A second objective is to find out how often these abnormally cold winters can be expected to recur, and, perhaps, some of the physical factors behind them. The historical importance of weather and climate, the necessity to assess its impact on today's soldier, and the critical geographic location of Germany to the military presented in this introductory chapter provides the rationale for this study. In the second chapter, the impact of temperature on individuals is reviewed in greater detail. Chapter 3 presents a general climatology of East and West Germany, thus providing the climatic background upon which the thesis is built. The statistical tests used to analyze the East and West German temperature records are presented in chapter 4. Chapter 5 discusses the results of those statistical tests, especially with regards to the implications of intraseasonal and interannual variability. Chapter 6 summarizes the results of this study, examines the possible implications of CO_2-induced warming on long-term military planning, and provides recommendations for improving the current procedure in which the Army records, plans, and utilizes climatic data.

Chapter 2
PHYSIOLOGICAL AND BEHAVIORAL RESPONSES
TO TEMPERATURE VARIABILITY

In order to gain a better appreciation of the potential
impact that low temperatures might have on soldiers waging a
conventional war in Germany, it is important to review the
literature concerned with the ways in which individuals
experience and react to extreme variations in temperature. A
commander who does not understand exactly how his soldiers
are effected by low temperature will never be able to
properly guard them against the rigors of German winters.
Military leaders at all levels must understand that there
are certain physiological and behavioral responses which
could increase an individual's ability to cope with adverse
atmospheric conditions. The first step in understanding
these responses is to know what initiates them.

2.1 Physiological Responses to Temperature
Change and Variability

When an imbalance occurs between the mean temperature
of the body and the ambient temperature beyond a certain
threshold, certain physiological changes take place within
the body. By understanding these changes, one can better
prepare for the adverse effects of low temperatures. From a

tactical perspective, leaders can only take the necessary
precautions to minimize the effects of cold when they
understand the process which influence the ability of their
soldiers to adapt to certain conditions. A useful toll to
describe the effect temperature variations have on the body
is the energy balance equation.

2.1.1   Energy Balance ₀

The manner in which human beings experience their
environment is directly related to their metabolism. In
order to understand human metabolism, one must understand
the energy budget of an animal when exposed to a particular
environment. The energy budget is a simple dynamical
relationship between energy and work, and is based on the
First Law of Thermodynamics. It has been established that
human metabolism varies within rather wide limits (more than
20° C) depending upon the relationship among the components
of the heat balance equation (Buettner, 1952; Burton and
Edholm, 1955). This wide range in metabolic temperatures
involve the transfer of heat between the skin and the
environment and is dependent on such factors as air
temperature, barometric pressure, temperature and emissivity
of solid ground, air speed, ambient water vapor pressure,
skin temperature, skin water vapor pressure, effective
surface area of skin, skin color, ventilation in lungs,
and clothing (Belding, 1970).

Mitchell (1974) defined the energy balance by the following equation:

$$M + W + K + R + C + E = S$$

where M = metabolic rate, W = work rate, K = rate of conductive heat loss/gain, R = rate of radiative heat loss/gain, C = rate of convective heat loss/gain, E = rate of evaporative heat loss, and S = rate of heat storage within the body. Each of these factors will be discussed below. Others who have similarly defined the energy exchange relationship between man and his environment include Mather (1974), and Winslow and Herrington (1949).

Metabolic activity is influenced by age, body size, build, sex, and possibly race. It varies with the amount of muscular work performed, the temperature of the environment, and the activity of the digestive system. Total metabolic energy production (M) is a combination of the basal metabolic rate (which is measured in standard resting condition), extra metabolism of food intake (usually 10-15% of the caloric value of the ingested food 3-4 hours after intake), extra metabolism of exercise, and extra metabolism of shivering (Mather, 1974). Sherman (1946) concluded that the center of metabolic activity is in the protoplasm of the active tissues of the body. Therefore, overweight individuals, who have inactive adipose tissue, have below

normal metabolic activity, women have a 5% lower metabolism, and trained athletes are normally 5% above normal metabolism. Metabolism tends to fall off progressively with age due to the decrease in the relative proportion of active vital tissue.

Mather (1974) found that 10-15% of the energy production of the human body goes to the performance of external work (W). The rest of the energy is produced as heat which must be dissipated if a constant body temperature is to be maintained.

The radiation term (R) is an extremely important factor in the energy budget. Budyko (1974) established that on a summer day the chief heat source for man is not his own heat production, but the incoming short wave radiation. Mather (1974) defined the radiation term as:

$$R = In \ Kpo \ Kcl \ (1-a \ (V-0.88))$$

where R = solar radiation, In = normal solar intensity, Kpo = coefficient which varies with posture and terrain, Kcl, a = clothing coefficient, and V = wind speed. Although many of these terms are easy to measure and define, some involve determining the surface area of an irregular shape such as the human body which adds increasing complexity.

The remaining terms in the energy balance equation deal primarily with mechanisms for the dissipation of heat. These

mechanisms include nonevaporative cooling (radiative and convective), evaporative cooling, and heat storage during peak metabolism.

Conduction and convection can be defined:

$$R + C = h \ (t_s - t_o) \ F_{cl}$$

where $h = h_r + h_c$ = linear radiative and mean convective heat transfer coefficient, t_s = average skin temperature, t_o = operative temperature (radiant temperature X heat transfer coefficient), and F_{cl} = combination of the thermal resistivity of air and clothing (Mather, 1974). Conduction and convection occur primarily in the respiratory tract and skin surface area.

Respiratory convection is a minor avenue of heat exchange, with the majority of respiratory heat exchange occurring through evaporation. Cena and Clark (1979) found that the latent heat transfer by evaporation from the respiratory tract and the surface of the skin is an essential mechanism for the regulation of the energy balance. Within certain temperature ranges (i.e., 29° to 35° C) a change in the rate of evaporation from the skin's surface is more substantial in heat regulation than a change in the overall heat production of the body (Budyko, 1974).

This energy balance equation is a useful tool for understanding the factors involved in thermoregulatory

behavior. In 1896,Rubner estimated that under average
atmospheric conditions, 44% of the body's heat was lost by
radiation to cold surfaces surrounding the body, 32% by
convective loss to the air from the skin and mucus, 21% from
evaporation from skin and mucus surfaces, and the remaining
3% by work done and the warming of ingested foods (Winslow
and Herrington, 1949). This generalization, however, is
based on many assumptions and is not representative of the
actual thermoregulatory behavior of man. In order to
determine this behavior, a more in-depth examination of the
physiological processes is required.

2.1.2 Thermal Detectors

Thermal stimuli is received by neurons which are
sensitive to temperature. This neural information enters the
central nervous system and is focused in the hypothalamus.
Various neural cold receptors appear to be sensitive to both
absolute temperature change and the rate of temperature
change (Webster, 1974). The perception of thermal stimuli
exists at birth, even in premature infants, indicating that
it is certainly innate and not acquired (Cabanac, 1974).
Cold thermogenesis is triggered when the sensations of cold
reaches a threshold intensity perceived by the hypothalamus.

Although these peripheral temperature detectors play an
important role in thermal behavior, it does not exclude
other detectors from also influencing behavior. Some

temperature detectors are located deep within the body core; these include the hypothalamus, thyroid, spinal cord, midbrain, and abdominal cavity. Thus, it is the multiplicity of thermal detectors which influence behavior and not just the temperature of the hypothalamus (Cabanac, 1974). In this manner, the importance of the general heat balance equation is realized. Peripheral cold reception and central warm reception are the principal sources of driving impulses for the thermal regulation of man (Benzinger, 1970). The relative importance of the deep body detectors is by no means a new discovery, especially with respect to the hypothalamus. In 1904, Kahn first suggested the presence of thermoreceptive structures in the brain. By 1938, Magoun confirmed the existence of such thermosensitive areas and localized them to certain parts of the hypothalamus (Strom, 60).

For a long time, scientists were in debate as to which temperature actually triggered thermoregulatory behavior. Most believed that the primary temperature being controlled was that of the deep central area; i.e., heart, lungs, abdominal organs, and brain. However, recent evidence has indicated that the temperature which appears to be controlled in man is simply the mean body temperature or the average temperature of all the tissues of the body (Mitchell et al., 1972). It may be the case that man achieves control of the brain temperature and deep core area temperature by

controlling the mean body temperature. This gives additive
importance to hypothalamic neuronal activity, which tends to
regulate the mean body temperature, and heat production in
exercise which is primarily located in the peripheral
muscles.

2.1.3 Cold Thermogenesis

Once a critical threshold in temperature is exceeded,
the body adopts behavior which tends to reestablish thermal
equilibrium. Cold thermogenesis represents man's primary
response to below normal temperature. It consists of three
basic responses (Webster, 1974; Table 2-1). First, somatic
nervous control is the response of striated muscles and is
commonly referred to as shivering thermogenesis. Secondly,
autonomic nervous control is a set of responses of the
sympathoadrenal system and is classified as a type of non-
shivering thermogenesis. Thirdly, neuroendocrine control
includes a group of responses of the anterior pituitary
which are also a type of non-shivering thermogenesis.
Alternately, responses to temperatures above normal tend
towards decreasing metabolic heat production, changes in
circulation of blood to vital organs and skin, and the
production of sweat.

Table 2-1

Effector pathways involved in cold thermogenesis in man and other large animals (Webster, 1974).

Control system	Relays	Transmitting agent	Target organ	Response
1. Somatic nervous system(-caudal hypothalamus and proprioreceptor system)	Somatic motor nerves	Acetylcholine	Striated muscle	Shivering increased tone
2. Autonomic nervous system (hypothalamus)	Sympathetic nerves –post ganglionic fibres –adrenal medulla	Noradrenaline Adrenaline	White adipose tissue* (β- receptors)	Lipolysis β oxidation increased turnover
			Liver and muscle (β- receptors)	Glycogenolysis and protein catabolism gluconeogenesis inhibits insulin
			Striated muscle (a- receptors?) Cardiac and smooth muscle (a- and β- receptors)	Potentiates shivering increased tone and rhythm
3. Neuroendocrine system (hypothalamus anterior pituitary)	Adrenal cortex	Cortisol corticosterone	White adipose tissue, muscle, liver	Potentiate a- β- receptors to catecholamines? increase net protein catabolism
	Thyroid	Thyroxine triiodothyronine	General	Potentiate action of catecholamines, increase synthesis of adenylcyclase

Shivering is a involuntary periodic contraction of a voluntary skeletal muscle. The generation of heat during shivering is a complicated chemical and physical reaction (Alexander, 1979). The stimulation of motor neurons leads to a depolarization of muscle and a rel..ase of intercellular bound calcium ions. These calcium ions activate a contractile protein known as myosin, an adenosine triphosphate (ATP), which is hydrolyzed quickly to adenosine diphosphate (ADP) and organic phosphates causing the muscle to contract. The ADP accelerates substrate oxidation resulting in a heat loss of the mitochondria in the muscle (Alexander, 1979). Although the potential for thermogenesis by shivering has been infrequently measured, it is usually several times the resting metabolic rate (Alexander, 1979). However, although striated muscles have the mass and the physiological capacity to produce sufficient heat for sustained periods, they do not have a copious reserve of domestic fuel. Himms-Hagen (1972) point out there is no longer any doubt that oxidation of fat plays a vital role in providing energy for sustained muscle activity. The above discussion on shivering implicates the importance of various chemicals in the generation of heat in striated muscles. Potassium and, more extensively, calcium are vital for the maintenance of physical activity (Greenleaf, 1979; Fig. 2-1). Another important factor is the rate of oxygen supply
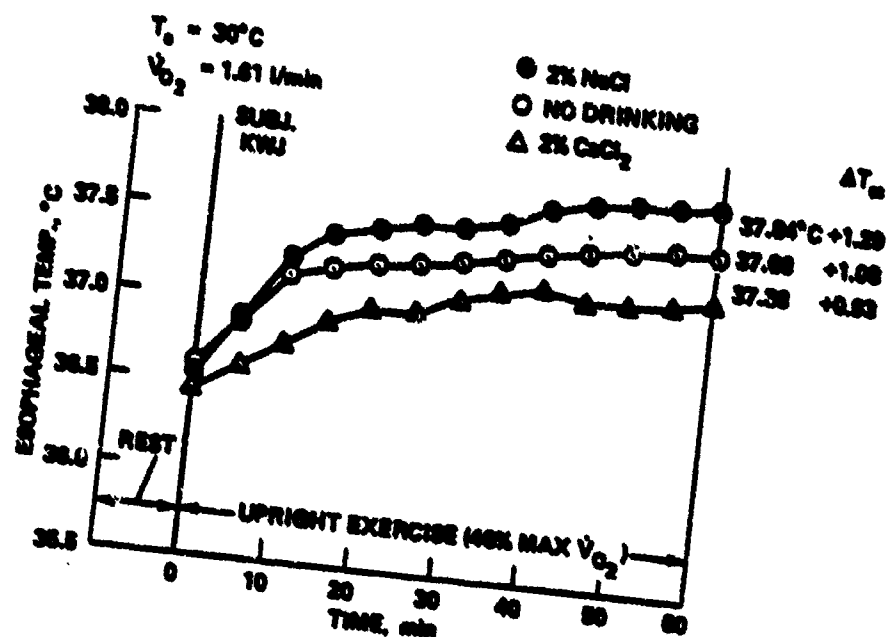
Figure 2-1. Esophageal temperature responses at rest during 60 minutes of submaximal exercise after ingestion of hypertonic sodium and calcium solutions (Greenleaf, 1979).

needed for the various oxidation reactions which must occur during muscle contraction.

Non-shivering thermogenesis include all other heat regulating mechanisms besides shivering. Davis (1961) found that man when exposed to prolong periods of cold, will show a gradually increasing change from shivering to non-shivering thermogenesis. Because muscular shivering increases the convective heat loss from the body surface, non-shivering thermogenesis is probably a more efficient mechanism for increasing heat production. The primary responses of non-shivering thermogenesis are changes in the circulatory system of the body (vasomotor response).

Vasomotor responses are mechanisms for controlling heat loss through the regulation of blood flow to the extremities. Deep sea fishermen can work with their hands immersed in water so cold that the hands of most people would be incapacitated by bouts of alternating numbness and pain. The blood flow to the hands of these fishermen must be more substantial and regular than those of sheltered individuals (Webster, 1974). Initially the autonomic response is vasodilation of the blood vessels. This is followed by vasoconstriction before the inner core temperature drops below a set threshold. In this way, vasomotor responses to cold are designed to serve two conflicting objectives, the need to minimize heat loss and

the need to maintain integrity of the tissue (Webster, 1974).

2.1.4 Factors Impacting on Thermogenesis

One of the primary limitation in man's ability to maintain thermoregulatory behavior is in the energy stores within the body. The level of energy reserves can play an important role in the maintenance of metabolism. There are various substrate stores for these energy reserves. Tissues store fats and carbohydrates. Blood can store a variety of fatty acids, glucose, lactate, glycerol, and ketone bodies (Alexander, 1979). The rest of this energy must be provided through food intake. It has long been observed that food intake increases during long term exposure to a cold environment. Conversely, an increase in temperature usually decreases food intake. This observation has led to the thermal theory of food intake (Brobeck, 1946). Although temperature may be a signal for food intake, it is a behavioral response based on energy balance and not temperature balance, and as such can not be classified as thermoregulatory behavior (Cabanac, 1974). In addition, the metabolized energy of food can not be used with the same efficiency as the energy reserves of the body. Normally a figure of 10% can be added to the basal metabolic rate to account for the effect of food intake, irrespective of the quantity and quality of the food eaten (Webster, 1974).

Brown adipose tissue (brown fat) can play a critical role in cold thermogenesis. Brown fat is a tissue with a high capacity for the production of heat. It is controlled from the central nervous system and represents a very small proportion of the total body weight. Alexander (1979) found that most mammals are born with brown fat, but few retain it past their infancy. He also found that brown fat plays a major role in non-shivering thermogenesis, especially in newborn animals. Bruck (1970) identified the special role of brown fat in warming the vital regions of the body. Smith and Horwitz (1969) discovered that brown fat also plays a significant role in the acclimation to heat and cold.

Besides energy reserves, other factors which influence thermoregulatory behavior include age, build, race, and anesthetics. Cena and Clark (1979) found that in the elderly and infirmed, sensitivity to both cold and heat is reduced, rates of metabolism and ability to raise rates of metabolism are depressed, and the clothing habits determined by 50 years of adult life are difficult to modify. Wyndham (1970) found that overweight people tend to be associated with heat intolerance. The effect of temperature on race has been contested for some time. Burton and Edholm (1955) wrote that "room temperature" for a man, in the USA meant about 24° C, in Britain about 18° C, and in Russia about 12° C. Some studies found variations in tissue insulation with race

(Hammel, 1964; Table 2-2). Others conclude that in no case was tissue insulation in any cold-adapted race or cold-acclimated individual unusually high (Webster, 1974; Fig. 2-2). One issue not so disputed is the ability of anesthetics (especially depressants) to depress physiological systems (Fig. 2-3). Vapaatalo et al., (1975) found that anesthetics depress shivering and non-shivering thermogenesis and can produce hyperthermia even under quite mild thermal conditions.

An area of perplexing concern is the thermo-regulation of the extremities. Protection of the extremities against cold is difficult. Hands and feet have a surface area which is very large in relation to their volumes. Since they are also at the extreme periphery of the vasomotor system, they are even more acute to temperature variations. Extremities of the body have very little metabolically active tissue. They are, therefore, almost entirely dependent on their blood supply for a source of heat. At temperatures below 0° C, vasodilation must occur in order to prevent freezing (Mitchell, 1974). Van Dilla et al., (1968) showed that it was impossible to provide adequate insulations for a man's fingers in the cold except when he is working at a high rate. This concern for extremities is even more important when viewed from the relative perspective of performance.

Table 2-2

Tissue insulation of man and some domestic animals in cold environments when blood flow to the cutaneous tissues is minimal (Webster, 1974).

	Species	Skinfold thickness mm*	Tissue insulation °C m².24h/MJ(Mcal)	Reference
Man	White man, normal weight	9.3	1.08 (4.51)	104
	White woman, normal weight	10.9	1.33 (5.56)	
	White man, obese	18.3	1.63 (6.82)	105
	Kalahari bushman	4.7	1.31 (5.48)	24
	Eskimo	5.8	0.98 (4.10	
Pig	Newborn	—	0.24 (1.00)	25
	Adult	—	1.69 (7.07)	106
Sheep	Adult	—	1.55 (6.48)	29
Cattle	1 month old	—	1.05 (4.39)	107
	1 y old, thin	3.7	1.48 (6.19)	26
	1 y old, fat	4.9	2.45 (10.25)	
	Mature fat	8.6	3.25 (13.60)	
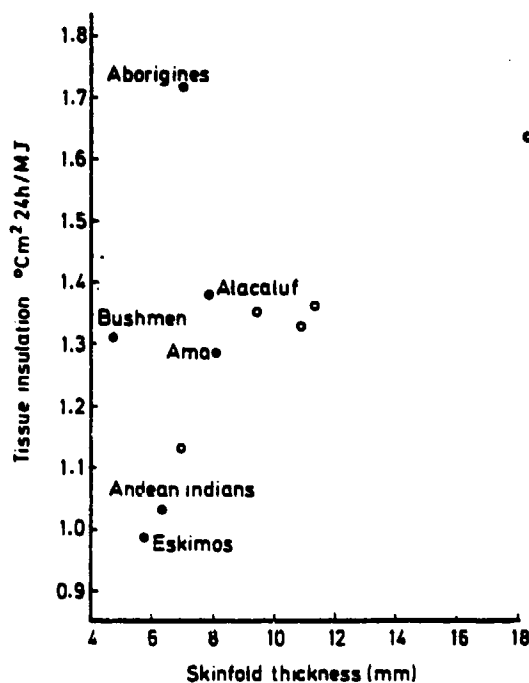
Figure 2-2. Tissue insulation in relation to skinfold thickness (Webster, 1974).
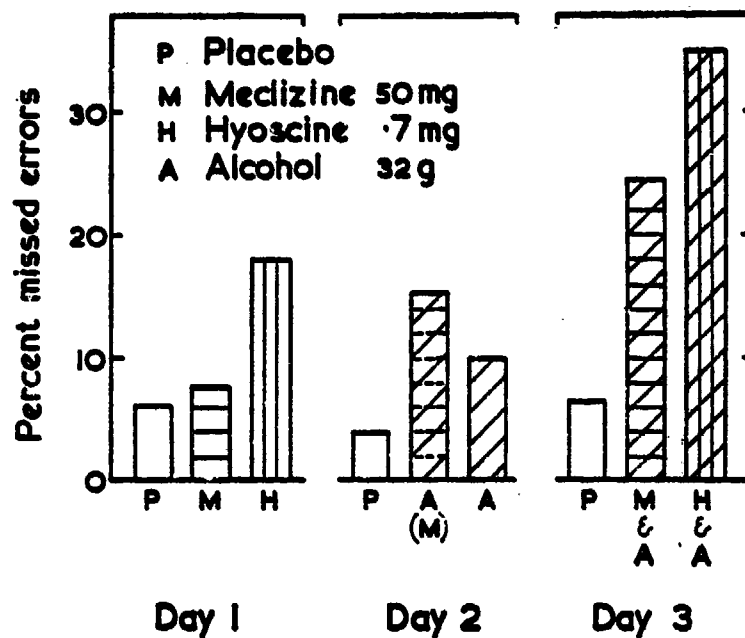
Figure 2-3. The effect upon a number-checking task of a combination of a drug to prevent motion sickness and alcohol (Poulton, 1970).

So far we have concentrated on man's ability to sense changes in temperature, and the different factors which influence the body's ability to cope with those changes. Man is a social animal and has adopted some behavioral reposes (both natural and cultural) to increase his efficiency in dealing with changes in his environment. One of the natural responses to cold exposure deals with the subject of acclimatization. The literature on this subject is laced with terms which are important in understanding the different processes at work.

Biological **adaptation** refers to the general morphological, anatomical, biochemical, and behavioral characteristics of an animal which promotes welfare and favors survival in a specific environment. **Habituation** is another term which is used to indicate a gradual reduction in the magnitude and the rate of the development of a thermogenetic response. Hart (1957) proposed that the term **acclimatization** should be used to describe physiological changes induced by a complex of factors such as seasonal and climatic changes, and **acclimation** should describe changes induced by a single environmental factor.

Bruck (1976) found that there was a downward shift in the threshold of shivering thermogenesis with repeated one hour cold exposures. Andjus **et al.**, (1971) found the hypothermic type of cold adaptation (commonly referred to as tolerance adaptation) does not need long exposure times for

the development of non-shivering thermogenesis. The levels
of this type of adaptation were found to be influenced by
physical fitness, but unrelated to any inborn racial
characteristic (Krog et al., 1960). The most convincing
subjects of this type of cold adaptation are the polar
explorers, Korean diving women, and North Atlantic Fishermen
(Table 2-3). The lower susceptibility of these groups is
probably both physiological (tolerance adaptation) and
psychological (reduced anxiety). Webster (1974) found that
the real significance of habituation appears in situations
when the thermal demand of the environment only temporarily
exceeds the threshold to stimulate thermogenesis. However,
as noted earlier, peripheral blood constriction and
shivering is extremely expensive in energy accounting. The
body possesses adaptation possibilities which are much more
efficient for heat stress than cold stress. Poulton (1970)
found that in individuals acclimated to heat there is a
greater flow of blood to the skin and sweating starts
sooner, is increased in quantity, and is considerably less
salty than in non-acclimated individuals.

2.2 Behavioral Responses to Temperature Variability

Man has also adopted a wide range of behavioral
responses to temperature change. As described above, the

Table 2-3

Temperature regulation in the hands of cold adapted racial groups and acclimatized workers compared with unadapted individuals (Webster, 1974).

Subjects	*Response to hand immersion in cold water*		
	Hand skin temp	*Heat loss/blood flow*	*'Hunting'*
Eskimos	Higher	Marked increase	Greater fluctuations
Arctic Indians	Higher	Marked increase	
Lapps	Not		
Norwegian fishermen	significantly higher	No change	Earlier onset
Gaspé fishermen	Higher	Increased	Earlier onset
Ama (Korean diving women)	Higher	Reduced	Abolished
Polar explorers	Higher		
US soldiers			

dominant mechanisms in the defense against over-warming tend to be autonomic in nature. Defense against cold tends to be concentrated in the behavioral mechanisms. These complex reactions can include motivation to increase clothing, the increase of heat production through exercise, or a search for a more favorable environment through displacement. Gagge and Herrington (1947) report that a change in posture is a primary behavioral response to cold. Contracted posture decreases surface area for heat loss and provides strong stimulus for exercise. In critical situations, behavioral and autonomic responses seem completely interchangeable . (Cabanac, 1974). They should, therefore, be assumed to be complementary and not competitive.

Observation of human life shows a progressive decrease of autonomic reactions with an increase in technology. Man finds and uses more and more thermoregulatory behaviors as his technolog develops. The most obvious thermal behavior in today's world is clothing. Clothing was initially adopted for its insulative function (Table 2-4). Clothes interfere in some way with the different avenues of heat exchange between man and his environment.

Original· cl ing was primarily a behavioral response to environmental stress. Today, the psychological function of clothes is more significant in our continued use of clothing (Mather: 4). If clothing is man's principal response to temperature change, then greater attention must

Table 2-4

Thermal insulation of garments
(Cena and Clark, 1979).

Item/Assembly	Insulation	
	m^2 K mW^{-1}	t cm^{-1}
Socks	1.5-5	0.02-0.06
Light underwear	8	0.1
Winter underwear (cotton briefs and short sleeve vest)	30	0.4
Shirt or blouse, short sleeve	30-40	0.38-0.44
Shirt or blouse, long sleeve	39-45	0.5-0.58
Light trousers	40	0.5
Heavy trousers	50	0.64
Sweater, long sleeve	26-57	0.34-0.74
Jacket	26-57	0.34-0.74
Heavy jacket or quilted anorak	76	1.0
Boiler suit or long winter underwear	77-116	1.0-1.5
Tights	1.5	0.02
Skirt	15-34	0.2-0.44
Light dress	26	0.34
Winter dress	100	1.3
Track suit	77	1.0
Arctic combat assembly	666	8.6

be paid to clothing design as climatic change and variability become more of a problem.

2.3 Measuring and Assessing Comfort

One of the critical factors in determining the effect of temperature change on man and its subsequent impact, is to obtain an adequate way of describing the pleasure or displeasure of thermal stimulae on a group of subjects. Although this appears to be an academic problem, the situation is far more complicated. The environments that man finds comfortable depends on both his level of activity (both internal and skin temperature), and insulation. In general the minimum metabolism is observed at 20° to 2..° C. Below or above this level there is a tendency for an increase in metabolic rate. However, this is a generalization based on laboratory conditions and is not applicable to man in his natural environment. Because of this, different indexes have been constructed over the years to measure man's comfort.

Early work in the field of human comfort resulted in the development of the effective temperature index (Houghten and Yonglou, 1923). Humiture, another index, was originally developed in 1937 (Heuener, 1959) and was revised once in 1960 (Lally and Watson, 1960) and later in 1979 (Winterling, 1979). During World War II the Climatological Branch of the Office of the Quartermaster General developed the thermal

acceptance ratio. But, the most familiar heat stress index
is probably the discomfort index (Thom, 1959), which was
later renamed the temperature humidity index. Although many
indexes are available, the current "best" is probably the
apparent temperature index developed by Steadman (1979).

Just as windchill combines the effect of low
temperature and wind, Steadman defined the term sultriness
to represent the combination of high temperature and
humidity. This combination of dry-bulb temperature and vapor
pressure results in an apparent temperature representing
what it "feels like" to a typical human. The scale of
apparent temperature is prepared for any combination of dry
bulb temperature, vapor pressure, wind speed and extra
radiation likely to be encountered. This gives this index an
applicability and range which was lacking in the earlier
indices. Variables considered in Steadman's apparent
temperature include heat generation and loss, fabric
resistance ratio, base vapor pressure, base wind speed,
direct solar radiation, diffuse incoming sky radiation,
albedo, terrestrial radiation, incoming extra radiation,
total extra radiation, proportion of body surface clothed,
correction for wind penetration within apparel, correction
for temperature, coefficient of fabric conductivity, surface
heat transfer resistance, core temperature, core vapor
pressure, and skin resistance. A simplified formula for
determining the apparent temperature outdoors in the sun is:

$$T_{pvg} = 4.5 + 1.02\ T - 100\ V^{10} + 2.8\ P -$$

$$5.8\ \phi^5 + 0.0054\ (Q_D + Q_d)$$

where T_{pvg} = apparent temperature, T = ambient temperature, P = ambient vapor pressure, V^{10} = wind speed measured 10 meters above the ground, ϕ^5 = fraction of solar radiation on a horizontal surface, Q_D = heat transfer direct insolation, Q_d = heat transfer diffuse radiation (Steadman, 1984).

Kalkstein and Valimont (1986) used Steadman's apparent temperature to develop a relative index which facilitates inter-regional comparisons. This index, the weather stress index (WSI), is created by computing the variations from the normalized apparent temperature and relating them spatially and temporally across a geographic area.

Steadman (1971) also improved Siple and Passel's (1945) windchill index by incorporating the factor of clothed skin into the equation. By multiplying the surface heat transfer coefficient by the difference between the temperature of the skin and the air, a more realistic index can be developed for cold environments.

2.4   Assessing Temperature Impacts

It is not surprising that performance of manual tasks tend to decrease in the cold. This is primarily due to the fact that fingers become numb when the skin temperature drops below 13° C (Ross, 1975). Kay (1949) found a drop in hand strength and dexterity when the temperature of the skin

of the hand fell below 15° C (Fig. 2-4). Lockhart (1966) and
Stang and Wiener (1970) also found an inverse relationship
between the skin temperature of the hand and performance.
Bowen (1968) found that memory and learned responses tended
to be impaired under cold conditions. Some behavioral
symptoms of the early stages of exposure are a lack of self-
control, low morale, paranoia, and poor memory (Ross, 1975).

At the other end of the scale, Poulton (1970) found
that a rise in body temperature to only 37.3° C reliably
impairs performance. He found two basic effects of an
increase in body temperature; first is an increase in the
number of errors, and second is a lowering of the level of
arousal (Fig. 2-5). Wyndham (1970) claims that heat stress
can lead to aggression, hysteria, or apathy. In any event,
the ability of temperature changes to affect performance is
critical in view of future climatic change.

There are physiological limits to man's ability to
regulate his body temperature. When these limits are
exceeded the results can be fatal. Once the body temperature
has fallen below 32.2° C, shivering is gradually replaced by
permanent muscular rigidity. The victim becomes confused and
gradually loses consciousness (Poulton, 1970). Death from
heart failure usually occurs by the time the deep body
temperature has fallen to 23.9° C (Molnar, 1946). The chance
of hypothermia happening is increased by fatigue, anxiety,
and inexperience in dealing with temperature extremes. Men
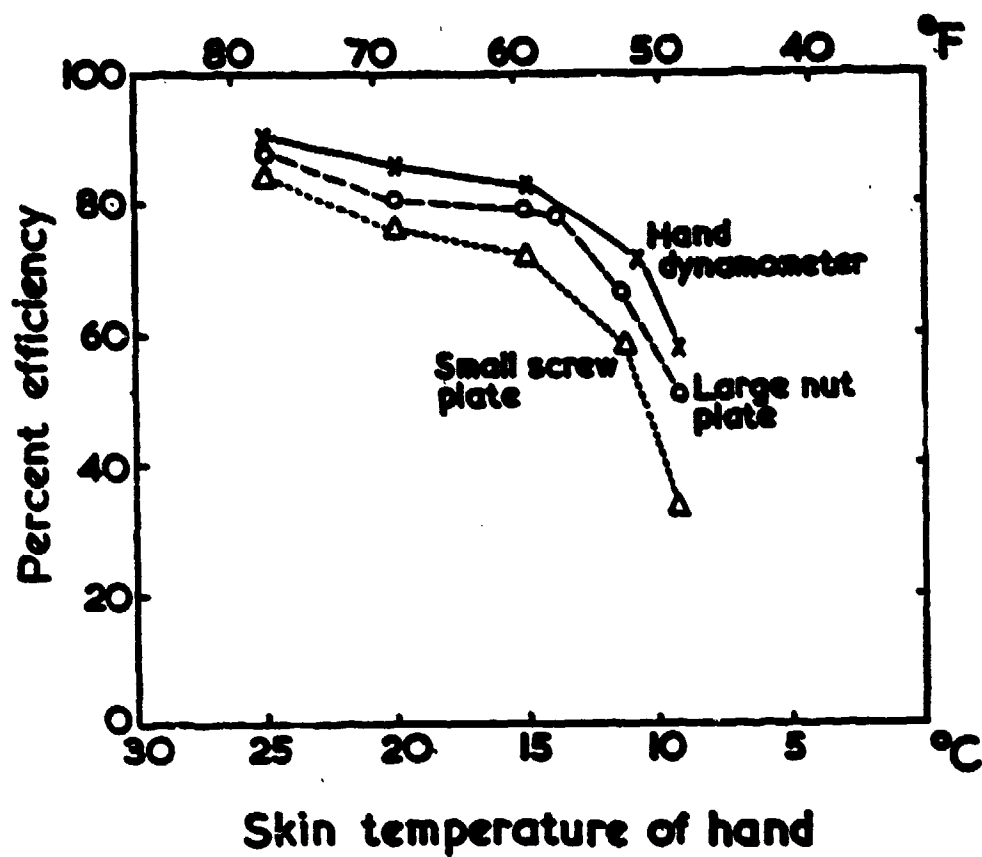
Figure 2-4. The average deterioration in various manual
tasks produced by a fall in the temperature of
the skin of the hand (Poulton, 1970).
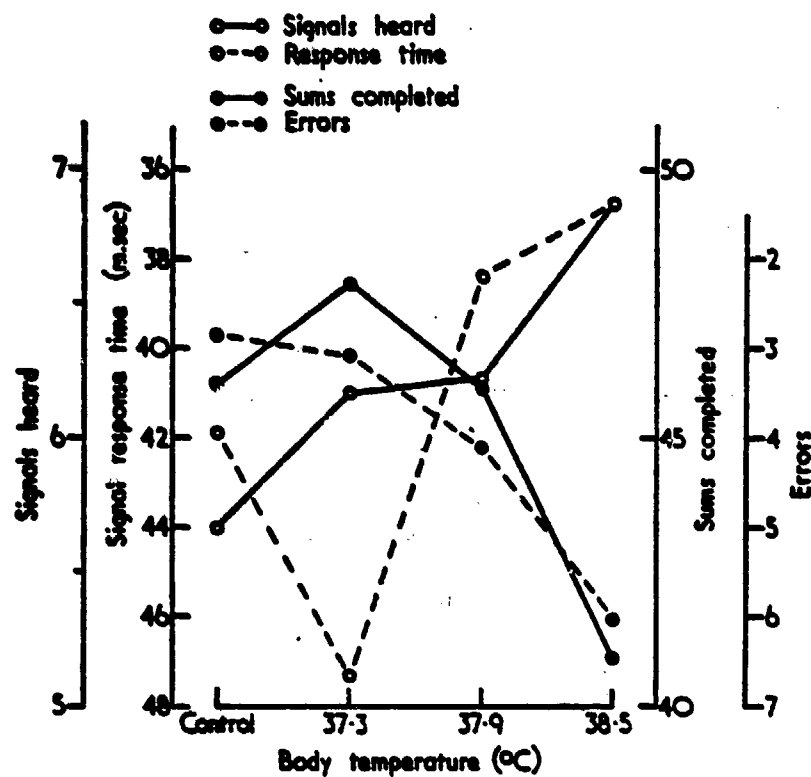
Figure 2-5.   The relationship between body temperature and
performance (Poulton, 1970).

are more susceptible than women, and children more than
adults. Greenleaf (1979) concluded that death ensues with a
drop in core temperature of 10° C, but it also follows with
an increase of core temperature of only 5° C. In this way,
overheating appears to be more critical than overcooling
(Gagge and Herrington, 1947).

There are factors which implicate temperature as a
contributor to mortality. Pneumonia is much greater in
months where the mean temperature is below -5° C (Winslow
and Herrington, 1949). This is also true for tuberculosis,
influenza, and bronchitis. The reason for this increase is
probably twofold. Behaviorally, during the winter people
tend to be indoors more, increasing the threat from
communicable diseases. Physiologically, a decreased blood
supply to the nasal and oral mucous under cold conditions
can influences variations in the body's resistance to
invasion (Fig. 2-6). Alternately, increased temperature can
provide an excellent breeding ground for disease, bacteria,
and vectors, and thus influence mortality.

2.5 Implications for Tactical Military Operations
     in Cold Regimes

Tactical operations force soldiers to operate in an
exposed environment under extreme thermal conditions for
extended periods of time and frequently without an adequate
food supply. This has been true for all past conflicts and
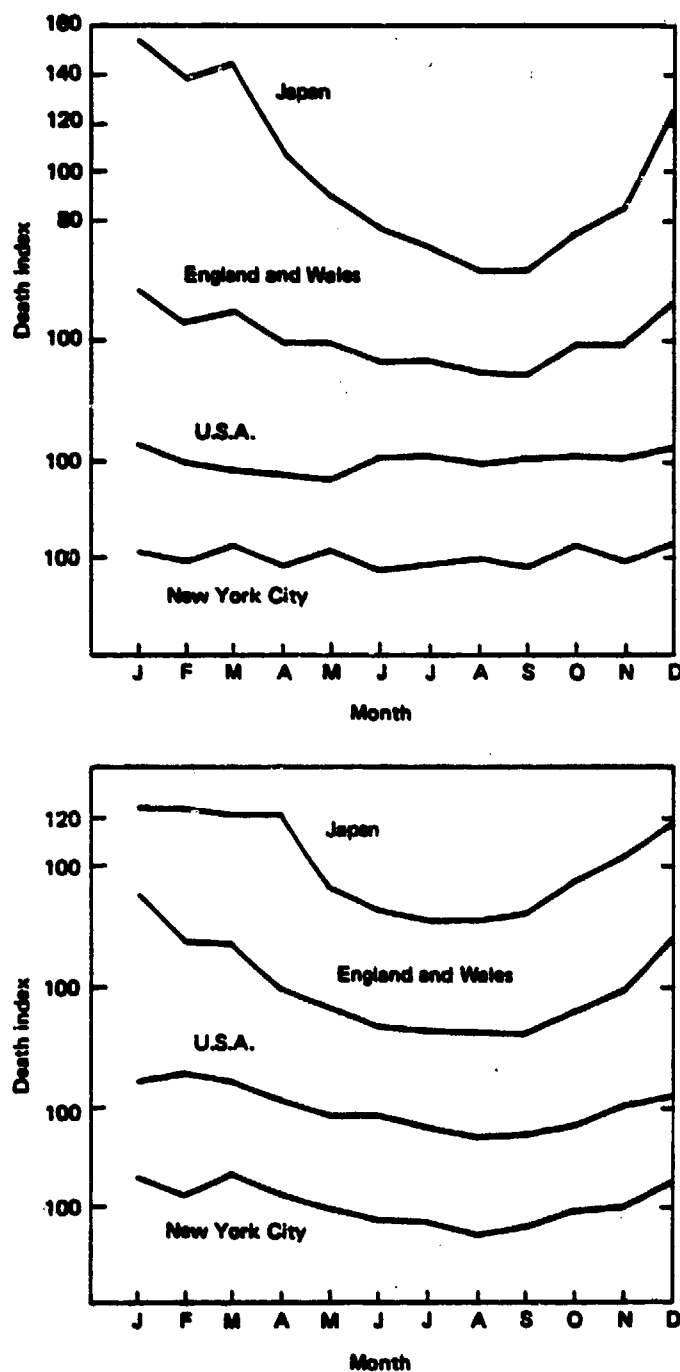
Figure 2-6. Seasonal fluctuations of total death by
countries for (top diagram) children under 1
year (1958 to 1962) and for (bottom diagram)
individuals over 70 (1958 to 1962.; Mather,
1974).

will undoubtably be true for future ones as well. There is
no doubt that extremes in temperature will have an
adverse impact on military operations. The problem is one of
assessing this decreased ability to execute the tactics
described in military doctrine. In this chapter it was noted
that a decrease in the skin temperature of the hand below
15° C resulted in deterioration in a variety of manual
tasks. When body temperature dropped below 37.3° C, both
memory and performance were substatially reduced (Poulton,
1970). If a simple relationship between mean body
temperature or skin temperature and ambient temperature
could be formulated, then one's ability to assess
temperature impacts on tactical operations would be greatly
increased. However, as previously noted, age, sex, body
size, metabolic rate, physical activity, clothing, and
energy stores all combine to produce an overall body
temperature which varies through the process of
thermoregulation to changes in ambient temperature.

An investigation of the local effects of cold on human
tissue reveals that the freezing point of tissues in man is
-0.53° C (Keatinge and Cannon, 1960). Therefore, in this
thesis 0°C will be used as an absolute threshold for
evaluating the possible effects of extreme cold periods on
tactical operations. As tissue temperature approaches 0° C
intense pain may be felt, resulting in damage to the small
blood vessels of the tissue. Prolonged exposure to

temperatures below this level can be considered detrimental to tactical operations. Potential for injury increases and performance levels decrease when soldiers are exposed to such extreme outbreaks of cold.

2.6 Summary

In general, and based on the review given in this chapter, one can expect the following impacts of exposure to extreme low temperature: decreased performance, decreased resistance to infection, and an increase in fatalities. Operating in extreme cold is costly in terms of physiological and economic energy consumption, especially for the small unit leaders. Knowning this, one can now look at a specific region of critical military importance and ask whether the variability of wintertime temperature in that region is sufficient to warrant concern for the conduct of tactical operations. The most critical area of the current defense doctrine is that of central Europe, and more specifically, Germany.

Chapter 3

STUDY AREA AND DATA

The Federal Republic of Germany (West Germany) and the
Democratic Republic of Germany (East Germany) are located
in central Europe. They extend from the North and Baltic
Seas (55° N) to the southern foothills of the Alps (46° N).
Köppen classifies the climate of this area as temperate
oceanic (Do). This implies an average temperature above 10°
C for four to eight months of the year and adequate and
reliable precipitation in all seasons. The large
temperature gradient between the subtropics and the
subpolar regions results, generally, in westerly flows over
the region throughout the year. Winter weather conditions
result from three major centers of action, and the
interaction of their associated air masses and frontal
zones over Germany. The Azores high directs mild, maritime
tropical air towards the north and east. The Icelandic low
is associated with vigorous frontal mixing of the maritime
tropical air from the Azores high and the maritime polar
air from the North Atlantic. The cold Siberian high,
normally located to the east of the Ural Mountains, can
occasionally extend west into Scandinavia and central
Europe. There are four major climate provinces in Central
Europe (Wallen, 1977): (1) the lowlands north of the
central European highlands; (2) the German highlands and

the Jura Mountains; (3) the northern Alpine foreland; and
(4) the Alps. These provinces are defined by their
latitude, distance from the ocean, and their altitude. A
good summary of the general climates of central Europe can
be found in Schüepp and Schirmer (1977).

3.1 Regional Temperature

Of critical importance to tactical operations is the
variability of temperature in a region. A convienient way
to organize the complexity of temperature variability which
exists over such a large region is to break it down into
climatological provinces (Table 3-1). In this way, one can
focus on those particular features which dominate certain
areas during specific times.

Hannover is located in the climatological province of
the lowlands north of the central European highlands. It
experiences a distinct pattern of temperature throughout
the three months that make up the climatological winter
season: December, January, and February. December
temperatures tend to be the highest of the winter season.
Hannover also tends to experience its least variable
conditions in the month of December. This can primarily be
attributed to the maritime effect of the Baltic and North
Seas. The low profile of the northern plain offers less
resistance to the normally westerly flow across Europe.

Table 3-1

Winter season mean monthly temperature and standard deviation of East and West German temperature stations representing the climatological provinces identified by Wallen (1977). Means and standard deviations (sd) in °C.

Station	December	January	February
Hannover	mean = 1.88	mean = 0.61	mean = 1.34
	sd = 2.35	sd = 2.97	sd = 3.10
Frankfurt	mean = 1.61	mean = 0.18	mean = 1.83
	sd = 2.57	sd = 3.01	sd = 2.79
Munchen	mean =-1.08	mean =-1.87	mean =-0.62
	sd = 2.72	sd = 2.85	sd = 2.80

The lack of friction enhances the maritime influence in this area resulting in generally higher temperatures (Wallen, 1977). Differential heating of land and water result in a phase lag of the annual temperature extremes of water and air. December temperatures therefore tend to be relatively high and less variable in this climatological province due to the moderating effect of the sea. This maritime influence decreases with distance from the coast resulting in somewhat lower and more variable temperatures beyond a coastal strip of 60 km. January temperatures tend to be the lowest of the winter season for this province. January is the month in which a high pressure regime tends to prevail over the central German uplands, advecting cold air from the continent rather than the predominantly maritime air from the west (Schuepp and Schirmer, 1977). February temperatures tend to be the most variable of the winter season. Snow cover in Scandinavia and Finland favors the formation of high pressure patterns to the northeast (Black, 1977). Baur (1947,1948, and 1963) found three major synoptic weather patterns which result in cold air advection from the northeast (Fig. 3-1). The synoptic pattern HNF represents the condition in which a high pressure cell located over Scandanavia results in cold air being advected from the northeast. Hess and Brezowsky (1951,1969) found that although this pattern could
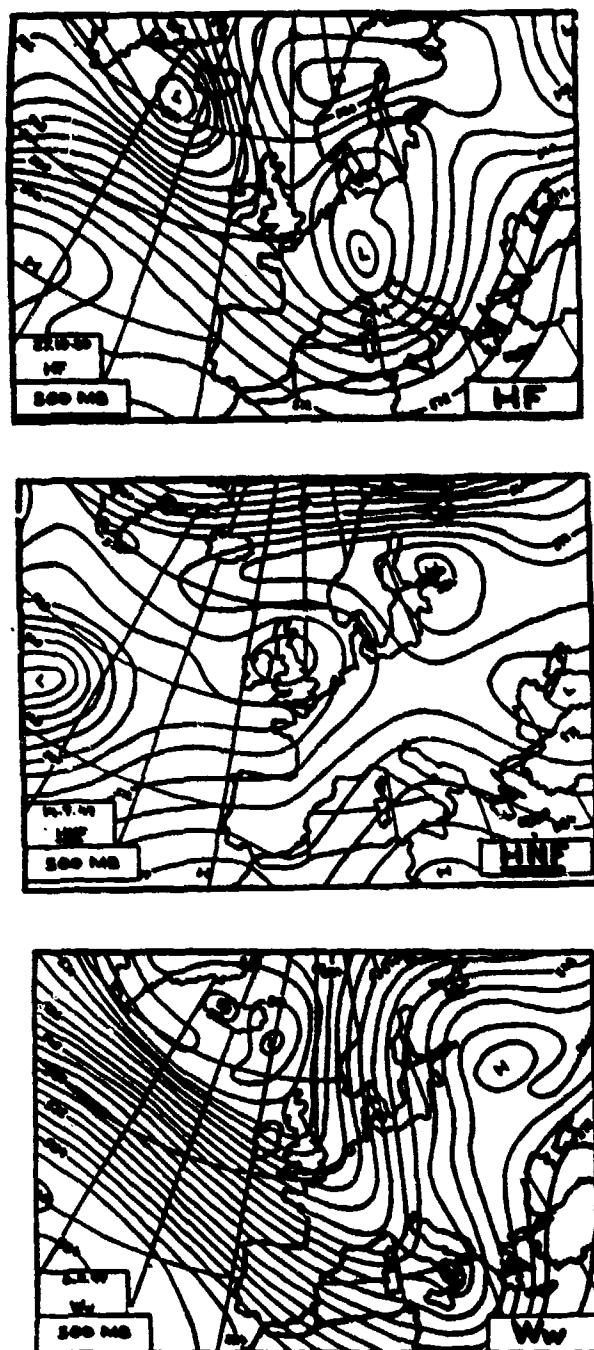
Figure 3-1. Meridional circulation characterized by above
normal pressure in the vicinity of Iceland and
above normal pressure in the vicinity of the
Azores Islands, resulting in cold air advection
from the north (Barry and Perry, 1973; after
Hess and Brezowsky, 1969).

occur in all months of the winter season, it was most prevalent in February when sea ice and snow cover reaches its maximum extent (Table 3-2). These large scale weather patterns, Grosswetterlage, represent major tren · in atmospheric events over a region during several c ; of essentially uniform weather characteristics (Baur,)47). However, this high pressure system over Scandanavia is not the predominant weather pattern in February. Normally, zonal flows result in strong Atlantic depressions bringing gales from the northwest (Schuepp and Schirmer, 1977). Although not as prevalent in this region, meridional flow can also result in warm air advection from the south (Fig. 3-2). Hess and Brezowsky (1969) found this type of warm advection to be associated with a southerly displacement of the Icelandic low and was most prevalent during mid-January (Table 3-2). Alternations between these contrasting weather regimes can explain much of the variability observed in wintertime, especially February temperatures in the German lowland province.

Frankfurt is located in the climatological province of the German highlands. It is situated in the Main River valley which generally runs east to west. December temperatures are characterized by relatively warm conditions. Widespread ground fog is common during this month, especially in the low lying river valleys (Black, 1977). The combination of ground fog and lack of snow cover

Table 3-2

Frequency of recurrence of synoptic scale meridional
weather patterns after Hess and Brezowsky (1969).
Frequencies given in percent.

Cold Air Advection.	December	January	February
A. From the North: type			
HN	3.2	3.5	3.5
N	1.9	2.6	2.5
TM	3.3	3.5	4.4
B. From the Northeast:			
HF	5.4	1.1	2.6
HNF	1.1	2.2	3.6
Ww	2.6	3.4	1.4
Warm Air Advection.			
TB	2.1	0.8	1.7
S	2.0	3.3	1.5
SE	0.9	0.6	2.3
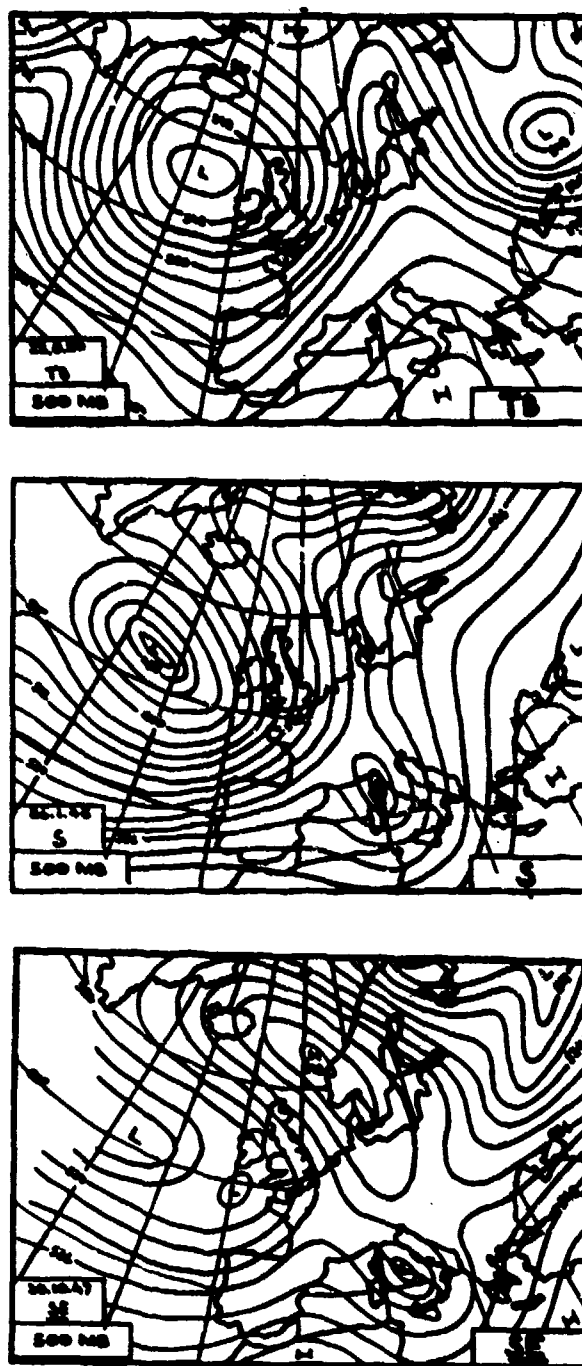
Figure 3-2. Meridional flow characterized by a southerly displaced Icelandic low resulting in warm air advection from the southwest (Barry and Perry, 1973; after Hess and Brezowsky, 1969).

creates the relatively mild conditions seen in December in
this climate province. January temperatures tend to be the
lowest and most variable of the winter season. Extended
periods of blocking which occur during mid-winter result in
an alternation between zonal and meridional flow. During
blocking episodes the trough line is normally located to
the east of Germany, resulting in cold air advection from
the north or northeast (Lamb, 1972; Fig. 3-3). Blocking
episodes are characterized by synoptic weathern pattern Ww
(Fig. 3-1). This condition results in cold air advection
from the north or northeast depending on the actual
location of the trough line in the north Atlantic and the
high pressure cell in western Russia. Also prevalent during
late January and February is cold advection from the north
characterized by synoptic patterns HN, N, and TM (Hess and
Brezowsky, 1969; Fig. 3-2). Between periods of blocking,
zonal flows force the cold surface layer, which forms
during nightly radiative cooling, to the east and replaces
it with mild marine air. The high frequency of extended
blocking episodes and dearth of zonal flows control the
average temperature of this climate province during
January. Unlike the lowlands to the north, February
temperature is the highest of the winter season in the
highlands. Snow cover reaches its maximum extent during
this month, and high pressure tends to prevail.
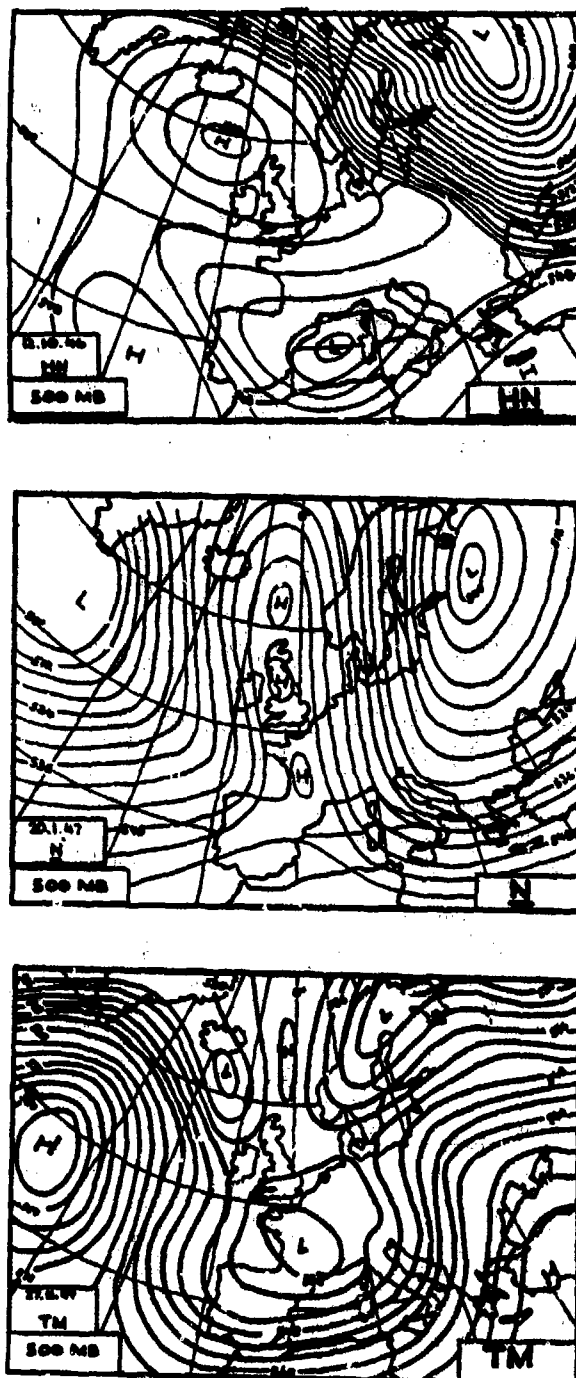
Figure 3-3. Meridional circulation characterized by a high
pressure system located over Scandinavia or
western Russia, resulting in cold air advection
from the northeast (Barry and Perry, 1973;
after Hess and Brezowsky, 1969).

This anticyclonic activity brings mild weather to the uplands while causing the lowlands to be much colder than normal (Schuepp and Schirmer, 1977).

The climatological province of the German alpine foreland is represented by the Munchen temperature station. Munchen is situated at the base of the Alps, which is the primary control of climate for this area. December temperature tend to be the least variable, January temperature tends to be the most variable, and February temperature is normally the highest of the winter season. Although a similar pattern is also observed in the German highlands, elevation and continentality cause much lower temperatures in the alpine foreland than the rest of Germany. Additionally, the numerous small lakes and marshes characteristic of this area make winters prone to low temperatures (Schuepp and Schirmer, 1977). Much of the insolation goes towards the melting or evaporation of ice and water, respectively, this leaving less energy available for the actual heating of the air and causing lower temperatures than would otherwise be expected.

In general, the following factors have a critical impact on the climate of East and West Germany. (1) The interaction of the three principle centers of action, the Icelandic low, the Azores high, and the Siberian high, result in alternating periods of zonal and meridional flow, advecting mild or cold air respectively into the area

depending on the strength and location of the various
weather systems. (2) Maritime influences tend to dominate
the study area, with a decreasing trend from the northwest
to the southeast. This maritime effect is modified by sea
ice and snow cover in the northernmost areas. (3)
Increasing elevation from north to south, along with the
numerous river valleys located in the German highlands and
alpine foreland play a large role in defining the complex
regional patterns of temperature and precipitation.
Although there are many other factors influencing the
climate of Germany, these are some of the more critical to
this study. The key task at hand is to try to determine the
nature of the climate variability of this area and to
identify the frequency and likelihood of extreme cold. Now
that the climatic factors which influence this area have
been presented, the temperature data can be investigated to
see if there are spatial or temporal patterns denoting the
way in which these factors interact. If such patterns can
be found and suitable preparations made for there
occurrence, then perhaps the vulnerability of tactical
operations to extreme wintertime temperature variations can
be reduced. First, however, the data to be analyzed must be
presented.

3.2   Data

The data base which was used in this study was taken
from two primary sources: the Department of Energy (DOE)
Data Bank (Fletcher et al., 1983) and the Ergebnisse der
Meteorologischen Beobachtungen. The DOE data Bank consists
of 3,425 temperature stations located throughout the
world. The data are given in standard units and in a
standardized format. Station histories, when available,
have been entered into the computerized data. These
histories include location, elevation, length of record,
and information concerning site changes. A potential
problem frequently noted in the data is that few stations
have maintained consistency in measuring throughout the
past 100 years. Consequently, older data were merged with
20th century data and statistical homogeneity tests were
undertaken in order to identify and, where possible, to
correct errors (Wigley et al., 1984).

For this study, stations were chosen primarily for
completeness and length of record, and secondarily to
obtain adequate spatial coverage. A total of 15 temperature
stations were selected (Fig. 3-4) with record lengths
ranging from 88 years (Potsdam) to 280 years (Berlin; Table
3-3). Very few of the temperature stations' records were
continuous. A large percentage of the stations show missing
data during the period between war years, 1914-1945. As
previously discussed, most errors due to station changes

Figure 3-4.   East and West German temperature stations.

Table 3-3

East and West German temperature station record data.

Station	Longitude	Latitude	First year	Last year
Kiel	54.3°N	10.0°E	1911	1980
Emden	53.3°N	7.2°E	1844	1980
Hamburg	53.6°N	10.0°E	1899	1980
Hannover	52.5°N	9.7°E	1856	1980
Kassel	51.3°N	9.5°E	1863	1980
Frankfurt	50.7°N	8.7°E	1757	1980
Trier	49.8°N	6.7°E	1788	1980
Stuttgart	48.8°N	9.2°E	1792	1980
Munchen	48.1°N	11.7°E	1781	1980
Friedrichshafen	47.7°N	9.5°E	1866	1976
Hohenpeissenberg	47.8°N	11.0°E	1781	1970
Berlin	52.5°N	13.4°E	1701	1980
Potsdam	52.4°N	13.1°E	1893	1980
Erfurt	51.0°N	11.0°E	1848	1980
Dresden	51.1°N	13.8°E	1851	1980

were corrected in 1984. The only known station change not included in this category is the move of the Frankfurt A Main station in 1961. This move resulted in a less than 1° longitudinal shift to the north and a change in elevation of 4 meters, the implication of which will be discussed later.

Missing temperature data was augmented by the collection of Ergebnisse der Meteorologischen Beobachtungen located in the Library of Congress, Washington, D.C.. These climatological yearbooks were scanned from 1899 to 1980 in order to complete the missing records as much as possible. The final data base was then subjected to the various tests reported in the next chapter to determine the German winter temperature variability for the past century.

Chapter 4

METHODOLOGY

A major concern in climatology is the study of climate
variations. History has shown that there is an important
need to study these fluctuations from the standpoint of
military operations. If one can identify and understand
such variations as they pertain to a specific geographical
area (e.g., Germany), then the chances of being adversely
effected by weather changes will be greatly minimized. From
a statistical viewpoint, the study of climatic fluctuations
can be considered a problem of time series analysis (WMO,
1966). If the non-randomness, such as trends and
periodicities, within a time series can be identified, then
important information on the frequency and nature of
extreme conditions may be obtained. For example, if there
is an oscillation in a time series, then the lowest points
in that time series would correspond to periods of
extremely low temperatures. By isolating these periods, one
may be able to determine information as to the underlying
factors contributing to these low temperatures. There are
certain optimum procedures which should be followed when
analyzing a climatological series (WMO, 1966). These
procedures are outlined as follows.

4.1 Homogeneity of Time Series.

The first step in analyzing a climatological time series involves the determination of the homogeneity of the series. Over the years, the methods and procedures for making meterological observations have changed from time to time. Some of those changes may include location moves, new instrumentation or changes in observing routines. There are also man-made changes, including urbanization, agricultural practices or landscape projects (WMO, 1966). Unless these changes are identified and taken into consideration, then any analysis of climate fluctuations may be in error. Valid variations in climatic parameters must be separated from those changes caused by man's activities and observational changes. Homogeneity tests are designed to identify discontinuities not induced by natural variation in the climatological record. In this respect, these tests tend to validate the data set and allow reliable conclusions to be drawn concerning climate variations.

There are two major categories of homogeneity test. A relative homogeneity test considers two or more climate time series, one pair at a time; an absolute homogeneity test compares the series under investigation with only one other series (Nie et al., 1975).

The Spearman rank statistic (r_s) was used to test for homogeneity of the series. It can also be used to test for randomness against the alternative of trend (WMO,

1966). The Spearman rank statistic is a non-parametric test which is frequently used when the frequency distribution of the time series cannot be determined. The value of rs can be tested for significance by using the Snedecor's F test for N-2 degrees of freedom (WMO, 1966; Clark and Hoskins, 1986).

Spearman's rs, along with Kendall's tau, can also be used as a test of relative homogeneity if the equations are corrected for the occurrence of tied ranks. This allows for the comparison of one station with every other station in the data record, thus increasing the probability of identifying any discontinuities in the climatological record. Spearman's rs differs from Kendall's tau in that tau is more meaningful when there is a large grouping of tied ranks, as compared to rs which provides a closer approximation of the product moment correlation when the data are more or less continuous (Nie et al., 1975). Both coefficients vary from +1.0 to -1.0.

4.2 Frequency Distribution of the Time Series

Another major step in the study of climatic fluctuations involves the determination of the frequency distribution of the time series. Each element of climate tends to have associated with it a distinctive frequency distribution. This distribution is a means of describing the population of the sample series. Statistical analyses

must be applied with knowledge of this distribution in order to avoid erroneous results. The basic statistics of a frequency distribution are the mean, variance, and standard deviation. Although the Central Limits Theorem states that when N is sufficiently large, the distribution of the mean of the samples will be approximately normal, many weather elements do not follow that rule (Bradley, 1976). It is, therefore, important to determine the frequency distribution before the climate series can be analyzed.

Temperature values have long been recognized as approximately representing a "normal" distribution (Barry and Perry, 1973; WMO, 1983). As such, temperature can be completely characterized by its mean and standard deviation. Futhermore, temperature values can be normalized using the standard z-transformation (Clark and Hoskins, 1986), thus allowing one to compare temperature values over a wide geographical area. Significance between the means of two periods or the difference between any two populations can be determined by the chi-square test (Clark and Hoskins, 1986).

4.3 Time Series Analysis

Once the homogeneity of the series has been established and the frequency distribution has been determined, then the time series can be subjected to various statistical tests to determine if there is non-randomness or

persistence present. Non-randomness in climatological series normally represents one of two major types of variations, trend or oscillation. Both of these possibilities must be investigated in order to determine the nature of climate variability for a particular region.

It often happens that the most likely alternative to randomness in a climatological series is that of trend (WMO, 1966). If trend is present, then it will show up as a discontinuity in the analysis of homogeneity as described in section 4.1.

The other type of climatic variation which can be present is an oscillation. Power spectrum analysis (Blackman and Tukey, 1958; Jenkins, 1961) was used for the purpose of evaluating this type of fluctuation in the time series. Also known as harmonic analysis, it was originally developed by Wiener (1930, 1949), and is based on the premise that a time series is composed of an infinite number of small oscillations spanning a continuous distribution of wavelengths. Theoretically, the first step is to compute the serial covariances (C_T) for all lags T=0 to T=M. Raw spectral estimates are then obtained directly from the serial covariances. In this study, the final spectral estimates were then computed by smoothing the "raw" estimates with a 3-term weighted average (Thom, 1958).

4.4 Other Statistical Measures

Occasionally, other statistical measures may be applied to the time series in order to aid in interpretation. Two of the more common techniques used in this study are moving average filters and regression analysis.

Moving average filters (Davis, 1973) are used to separate the noise from the signal in the climatological series. Ordinary moving averages pass the longest wavelength with little effect on the amplitude, filtering much of the variation in the shorter wavelengths. This is done to simplify the data so that longer, more important, variations can be easily recognized. Two types of moving averages were used in this study. A five-term simple moving average was used to filter the short term variation in the climate series, and an 11-term simple moving average was used to filter the noise associated with the 11 year sunspot cycle.

Regression analysis (Nie et al., 1975) was also used to investigate the relationship between various climatic elements and mean hemispheric circulation patterns. This was done to see if these circulation patterns could be used to explain the variations observed in the time series. Correlation coefficients (r) and the coefficient of determination (r^2) were used to examine the unexplained variance which existed when the values of the two variables were fitted to a linear function.

The above series of tests represent a typical procedure used to investigate the nature of climatic variations. These will now be applied to the East and West German temperature data.

Chapter 5

RESULTS AND DISCUSSION

The results of the analyses which follow must be viewed
in light of the factors which are operating on the climate
of Germany over the course of the winter season (chapter
3). These factors will play an important role in
understanding the variability which exists in the
temperature record for this region.

5.1   Homogeneity and Stationarity

Using Kendall's tau and Spearman rs rank tests (WMO,
1966), each station was tested against every other station
in order to determine the relative homogeneity of the
series (Table 5-1). The values for the Spearman correlation
coefficients tended to be higher than that of Kendall's
tau. This can be partially explained by the continuous
nature of the data and the general lack of a large number
of ties at each rank. All stations reflected homogeneity at
the 99% significance level indicating the relative
stationarity of the data, the general lack of persistence,
and the presence of randomness in the series. Since actual
values of rs are closely related to the product-moment
correlation coefficients, they can also be used as a

Table 5-1

Relative homogeneity test for German temperature stations.
Values indicate r X 100. All stations are significant at
the 99% level unless indicated by NS (not significant).

Spearmans\Kendall	KI	HA	EM	HN	KA	FF	TR
Kiel (KI)	***	82	84	65	67	51	66
Hamburg (HA)	93	***	83	75	69	54	63
Emden (EM)	95	92	***	78	76	70	59
Hannover (HN)	83	86	90	***	72	68	56
Kassel (KA)	85	83	89	87	***	85	73
Frankfurt (FF)	67	69	86	85	96	***	89
Trier (TR)	82	79	74	72	90	97	***
Stuttgart (ST)	64	57	74	80	86	96	99
Munchen (MU)	61	54	71	71	87	91	94
Friedrichshafen (FR)	47	53	64	64	81	83	86
Hohenpeissenberg(HO)	60	63	76	78	87	86	91
Berlin (BE)	87	89	92	86	87	82	78
Potsdam (PO)	82	84	95	90	90	80	80
Erfurt (ER)	80	77	89	88	93	94	86
Dresden (DR)	77	69	86	87	90	93	NS

Table 5-1 (continued)

Spearmans\Kendall	ST	MU	FR	HO	BE	PO	ER	DR
Kiel (KI)	46	47	34	44	73	71	63	60
Hamburg (HA)	45	41	39	47	79	75	63	56
Emden (EM)	57	55	49	58	79	83	74	71
Hannover (HN)	63	54	47	61	73	79	74	73
Kassel (KA)	68	72	64	70	71	77	81	77
Frankfurt (FF	85	77	65	67	66	64	83	80
Trier (TR)	94	82	69	74	59	62	67	NS
Stuttgart (ST	***	71	69	73	58	64	77	70
Munchen (MU)	86	***	74	72	55	55	64	64
Friedrichshafen(FR)	87	89	***	61	43	46	57	60
Hohenpeissenberg(HO)	91	88	80	***	55	60	63	63
Berlin (BE)	75	72	59	73	***	86	73	80
Potsdam (PO)	80	72	63	78	94	***	79	80
Erfurt (ER)	92	82	75	82	87	92	***	85
Dresden (DR)	86	80	76	81	93	93	96	***

relative measure of similarity between stations (Nie et al., 1975). In this way, although all stations are subjected to the same statistical tests, repetition in the discussion of results will be minimized by reporting on only those stations representing major groupings.

The criterion used for grouping temperature stations was a Spearman's rs above 0.85, reducing the number from 15 to 5: KIEL (which includes Hamburg, rs=0.93), BERLIN (which includes Potsdam, rs=0.94; Dresden, rs=0.93), HANNOVER (which includes Emden,rs=0.90), FRANKFURT (which includes Kassel, rs=0.96; Trier, rs=0.97; Stuttgart, rs=0.96; Erfurt, rs=0.94), and MÜNCHEN (which includes Friedrichshafen, rs=0.89; Hohenpeissenberg, rs=0.88). The fact that these stations are very highly correlated is not surprising. Schuurmanns (1984) and Meyer zu Düttingdorf (1978) found that the European community was, in general, so small and under the influence of the same circulation types that large differences in timing, as well as sign of temperature changes should not be expected. Temperature stations seemed to group primarily according to geographic location. Other factors influencing the groupings were distance from the maritime source, elevation, and physiographic province.

The results of the temperature homogeneity test indicate that the stations are relatively free from errors associated with non-consistent measurement techniques or

influences of man-made environments. This implies that the station data are homogeneous and that any variation seen in the time series can be attributed to natural changes in the climatic parameters.

5.2   Time Series Analysis

One alternative to randomness in climatological data is that of trend. The presence of trend in the series was tested with the Spearman's correlation coefficient in a test for absolute homogeneity. Results for temperature stations are given in Table 5-2. Values less than 0.5 indicate that there is no persistence in the series which can be associated with a trend. Here, all values were significant at the 99% level and all correlations were sufficiently low to rule out the presence of trend.

Another possible deviation from randomness is the presence of an oscillation in the data, which was tested through power spectrum analysis. Analysis of a power spectrum uses hypothesis testing as a means of fitting varied hypotheses to the spectrum and conducting statistical tests which either reject or fail to reject the original hypothesis (Clark and Hoskins, 1986). In this case, a null hypothesis was first established which assumed the dominance of white noise or randomness in the series. Temperature stations were then checked for the presence of white noise in the series using the Kolmogorov-Smirnov test

Table 5-2

Spearman's correlation coefficient (rs) used as a test for randomness against the alternative of trend for German temperature stations. All values are significant at the 95% significance level.

Temperature	rs
Kiel	0.30
Hannover	0.12
Frankfurt	-0.11
Munchen	0.06
Berlin	-0.01

(Table 5-3). This test for the raw data indicated the presence of white noise as the dominant characteristic of the series of both Munchen and Berlin. Therefore, the null hypothesis is not rejected and it is concluded that these series are predominantly random. In contrast, the smoothed data obtained much higher values for the Kolmogorov-Smirnov test, all well above the 95% significance threshold.

Because the null hypothesis of randomness was not rejected, a new null hypothesis is established which assumes the presence of Markov red noise (persistence) in the time series. This hypothesis is then tested through the lag one serial correlation coefficients. The shape of a power spectrum which contains Markov persistence can be represented by an exponential relationship (WMO, 1966). The coefficients for lags one through three are then checked to see if they approximate this exponential relationship. If they do, then the null hypothesis is not rejected and it is assumed that Markov persistence is present in the series. Tests for autocorrelation were conducted on the time series for lags 1, 2, and 3. The values of each lag were checked to see if subsequent lags represented an exponential relationship (e.g. $r_2 = r_1^2$; $r_3 = r_1^3$). Because the lag one correlations were so low, this exponential relationship was only mildly representative of both the raw and smoothed temperature station series (Table 5-4).

Table 5-3

Test for randomness in the German temperature station record for "raw" and "smoothed" time series using the Kolmogorov-Smirnoff test.

"Raw" Time Series	Kolmogorov-Smirnoff	95% Level
Kiel	0.160	0.123
Hannover	0.158	0.121
Frankfurt	0.144	0.113
Munchen	0.071	0.096
Berlin	0.072	0.090
"Smoothed" Time Series		
Kiel	0.793	0.126
Hannover	0.774	0.127
Frankfurt	0.788	0.117
Munchen	0.702	0.099
Berlin	0.770	0.090

Table 5-4

Autocorrelation of lags 1 to 3 for "raw" and "smoothed" German temperature records as a test for Markov persistence. All correlations are significant at the 95% level.

"Raw" Time Series	Lag 1	Lag 2	Lag 3
Kiel	0.10	-0.02	-0.16
Hannover	0.16	-0.00	-0.01
Frankfurt	0.16	0.02	0.02
Munchen	0.03	0.00	-0.58
Berlin	0.05	0.02	-0.03

"Smoothed" Time Series	Lag 1	Lag 2	Lag 3
Kiel	0.03	-0.04	-0.02
Hannover	0.15	0.00	-0.12
Frankfurt	0.18	0.06	0.01
Munchen	-0.34	-0.12	0.05
Berlin	0.07	0.01	-0.55

Since the Frankfurt series had the largest lag one serial correlation and, therefore, the best representation of an exponential relationship, the presence of Markov red noise was assumed for the Frankfurt series and the various harmonics were checked for significance. Moderately high peaks were located at 2 and 8 years. However, these peaks were only significant at the 80% level. The Frankfurt temperature series was also run through an 11-term simple running mean. This smoother was used to filter any noise which may be associated with the 11-year sun spot cycle in an attempt to further isolate a signal and increase the significance (WMO, 1966). Again the results indicated the presence of red noise, but below the 85% significance level.

This somewhat surprising nonpersistence in the temperature record for Germany has been found by other authors. Von Rudloff (1967) concludes the nonperiodicity of the variations of all climatic elements over the whole of Europe is so strong that periodic changes most often are merely to be considered an unimportant computational result.

5.3   Variability

One of the most critical aspects of German winter climatology is its variability. As previously noted, many tactical operations have met their demise due to the sudden

and sometimes prolonged excursions of poor weather into this area. As long as weather remains consistent, personnel will acclimate and tactical plans will reflect those conditions. It is when the variability is high that the impact is greatest felt on the battlefield. Not only is high climatic variability common in Germany, it is, in fact, representative of the climate. Variability can be examined on time-scales from months to decades. This section will study this critical aspect of German winter climatology by analyzing intraseasonal variability, interannual variability of December temperatures, January temperatures, and February temperatures, and total variability within the winter season of the entire record.

For illustrative purposes, discussion of variability will focus on the Frankfurt station. Because of the dominance of white noise in the raw temperature series, the data were smoothed using a 5-term simple running mean discussed in chapter 4 in order to isolate the signal from the noise. Although not discussed, similar analyses were carried out for Kiel, Hannover, Munchen, and Berlin with the same general results. Frankfurt is located in the central German uplands. It is approximately half-way between the Baltic Sea and the foothills of the Alps, and as such represents a good compromise between lowland plains station, and the continental stations located further inland. Frankfurt, therefore, is believed to be

representative of the average conditions of Germany and
will be used to describe the interannual variability of
German winter temperature.

Although there appears to be a trend in the smoothed
temperature record for Frankfurt, especially in January, as
noted earlier the red noise present in this record is weak
(Table 5-4). In addition, trends play a relatively minor
role in temperature impacts on exposed personnel. What is
most critical is the absolute temperatures, which result in
the various physiological and behavioral responses
discussed in chapter 2. The large gap occurring in the
series between 1790 and 1821 represents a period of missing
data, possibly in part caused by the general upheaval
associated with the French Revolution and the campaigns of
Napoleon during this period.

Intraseasonal temperature variability of each of the
winter months is illustrated in the normalized temperature
series for Frankfurt (Fig. 5-1). The standard deviations
(from Table 3-1) for this station are: December, 2.57;
January, 3.01; and February, 2.79. The Frankfurt smoothed
temperature record can be characterized by large
intraseasonal variability throughout the entire record.
This is evident in the large month to month alternations
between below normal and above normal temperatures. For
example, in December of 1766 Frankfurt had a mean monthly
temperature of 4.8° C below normal. The following month,
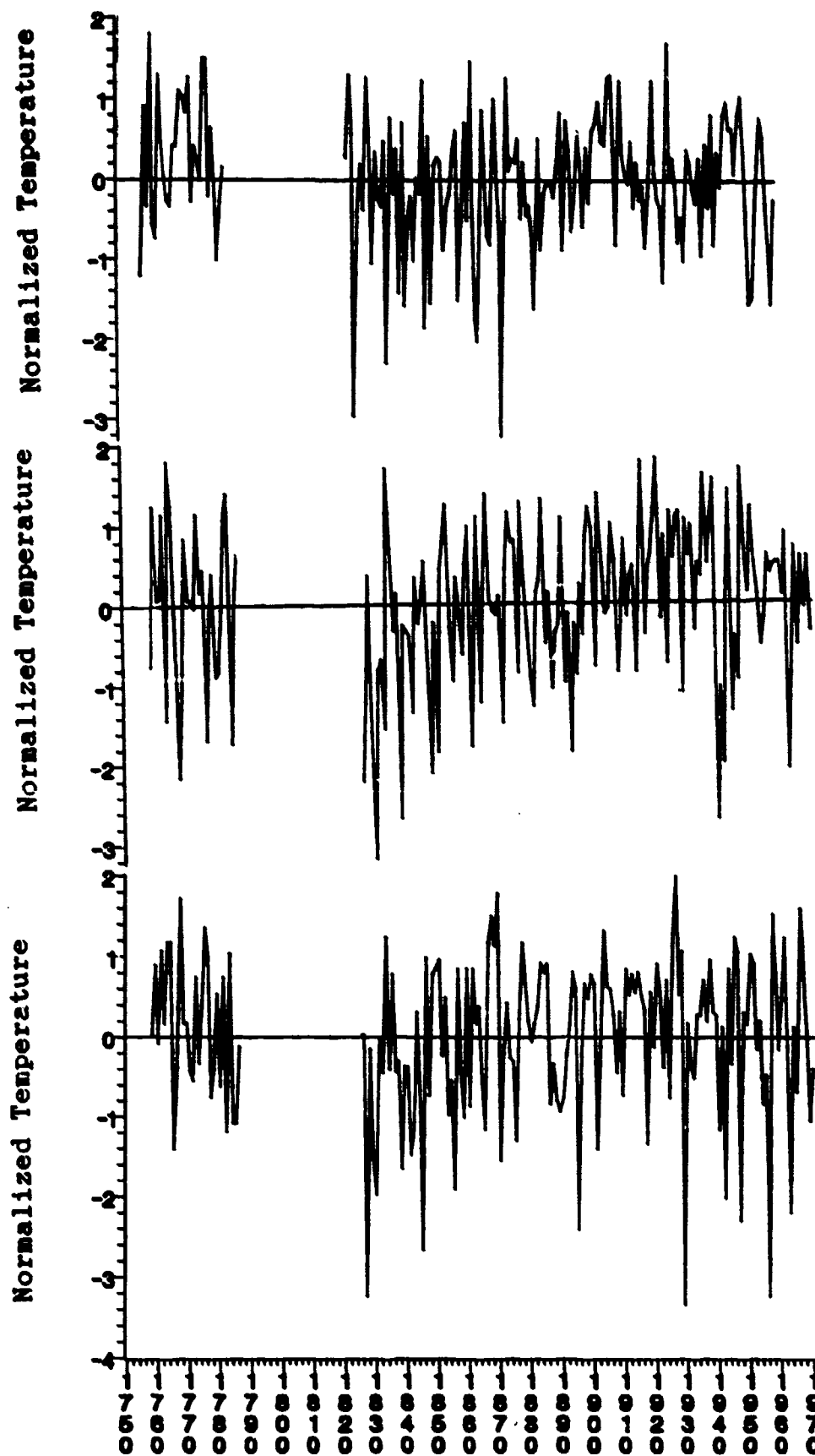
Figure 5-1. Normalized smoothed Frankfurt temperature time series. Top, December; middle, January; and bottom, February.

January 1767, mean monthly temperature fell to 6.6° C below
normal. Then in February 1767, mean monthly temperature
rose to a high of 4.7° C above normal. In 1880, December
mean monthly temperature was 2.3° C above normal, January
mean monthly temperature was 3.0° C below normal, and
February recorded 0.6° C above normal. A more current
example of this variability occurred in 1965 when monthly
temperature varied from 1.3° C above, to 0.6° C below, to
3.2° C above normal over the course of the winter season.

.Considerable interannual temperature variability is
also observed in the same time series (Fig. 5-1). The
importance of interannual variability can be illustrated by
the January mean monthly temperature between 1930 to 1942.
For nine years Germany experienced above normal
temperatures during this month. As Hitler's army prepared
for its invasion of Russia, three successive winters of
below normal temperatures (1940-1942) fell upon the German
army including Januaries with temperatures of
-8.0° C, -3.0° C, and -5.9° C. The results are recorded in
the annals of history.

What becomes evident from the examination of the
intraseasonal and interannual variability is the fact that
large temperature variations are not the exception, rather
the rule for this area. German winter is characterized by
high variability of all climatic elements (Rex, 1950; Van
Loon and Rogers, 1979). Tactical leaders at all levels

should be aware that this area is prone to sudden, and sometimes prolonged, periods of below normal temperatures. These periods normally last for several days, but can result in low temperatures lasting over the period of two to three weeks (Hess and Brezowsky, 1969). It therefore becomes important to understand the synoptic scale weather patterns and conditions which characterize this variability, especially as related to extended periods of cold. If one can identify the frequencies and probabilities of this variability, then perhaps leaders will be less likely to be caught off guard by an unsuspected change in German weather.

Since our principal concern is with prolonged periods of cold, it is important to isolate those conditions that bring abnormal cold into Germany. Referring back to Fig. 3-1 and 3-2, cold air can be advected into this area from two principal directions: north and northeast. Braur (1947, 1948, 1963) found that these large scale weather patterns most frequently occurred during periods of meridional flow. He also found that meridional flow was associated with increased variability of temperature. Other authors have found a similar relation between meridionality and variability. For instance, Diaz and Quayle (1980) found an increase in variability for meridional periods in the continental United States. Lamb (1977) noted that the variance in winter temperatures in western Europe was

greatest in periods with minimum westerly winds. However, Van Loon and Williams (1978) did not find such a simple connection between variability and temperature trends in their study of western European stations.

Since meridional flows in this area can create either very cold air advection from the north or warm advection from the south, there may exist a distinct relationship between meridional flow and the variability of temperature. This can be tested by comparing the variability of zonal and meridional periods with the variability of the entire record.

Kalnicky (1974) identified two distinct time periods in the northern hemisphere mean temperature series. These periods were associated with changes in hemispheric circulation from a more zonal flow (1900-1950) to a more frequent meridional flow (since 1950). Variability of German winters can be studied within these two periods to see if a relationship exists between hemispheric circulation and variability on a regional scale.

Temperature variability (Table 5-5) was calculated for the entire period of the record and also during those periods where either zonal or meridional regimes prevailed. The differences between the standard deviations were tested for significance using Bartlett's test for the constancy of variability (WMO,1966). Periods which contained missing values in excess of one half the record length were

Table 5-5

Comparison of temperature variability as defined by the mean standard deviations of periods of meridional and zonal circulation regimes given by Kalnicky (1974) and Rogers (1984). All refers to the entire period of record. Values not significant at the 95% level are designated as NS.

| Station | All | Kalnicky (1974) | | Rogers (1984) | |
| | | meridional | zonal | meridional | zonal |
		1950-70	1900-50	1955-70	1920-40
Kiel	1.73	NS	1.97	NS	3.37
Hannover	1.90	2.90	2.80	4.32	4.52
Frankfurt	1.87	3.58	2.31	4.17	3.58
Munchen	1.82	3.03	2.41	4.25	3.72
Berlin	1.95	3.23	2.55	4.63	3.96

excluded from the calculations. Only in one instance (Kalnicky's zonal period for Kiel) does Bartlett's test fail to indicate a significance above the 95% level. Therefore, the contrast in variability between the various periods appears to reflect a genuine difference. On average, the variability of the meridional period was 1.2° C greater than the variability of the entire record. In comparison, the zonal period only produced variabilities in the range of 0.6° C greater than the entire period.

Kalnicky's circulation regimes were based on data collected over the entire northern hemisphere. Since this study is interested in the region of central Europe, other indices can be used to measure the relative meridional and zonal circulation over the North Atlantic which would be more applicable to East and West Germany.

Rogers (1984) studied the North Atlantic Oscillation (NAO), which can be used as a measure of the zonal wind strength across the north Atlantic. Visual examination of the NAO index in his study indicates a clearly zonal period (1920-1940), and a meridional period (1955-1970). The variability of the NAO index within these periods was then compared with the German temperature series (Table 5-5). Roger's meridional period, on the average, had a variability 2.3° C greater than the entire record, while zonal period variability tended to be on the order of 1.9° C greater.

Another indication of the magnitude of this variability can be seen in the recurrence of extremely low temperatures. In chapter 2, it was noted that performance showed a marked decrease when hand temperature fell below 15° C. A threshold can be established upon which to investigate periods of extreme cold. Human tissue freezes at -0.53° C (Keatinge and Cannon, 1960). Therefore monthly temperatures below 0° C can indicate those cold periods in which prolonged exposure would have a substatial impact on tactical operations. Average frequencies of recurrence of these extremely cold months can then be calculated within the zonal and meridional regimes identified in Rogers (1984; Table 5-6). Stations were chosen to represent each climatic province. Results indicate that these extremely cold months may occur in both zonal and meridional periods. However, the frequency of recurrence tends to be greatest during meridional periods. The northern stations tend to indicate a very significant difference in the number of temperature events between zonal and meridional periods. Although somewhat less significant, this same relationship can be seen in stations located in the German uplands. Stations located at higher elevations in the alpine foreland do not reflect a relationship between meridional flows and low temperatures, suggesting the relative importance of topography in shaping the regional climate. In addition, these cold periods tend to occur most often

Table 5-6

Frequency of recurrence of mean monthly temperature below 0° C during meridional (1955-1970) and zonal (1920-1940) regimes identified in Rogers (1984). Frequencies given in percent. Significance levels denote the difference between meridional and zonal periods and are calculated using chi-square.

Station	Period	December	January	February	sig.
Hannover	meridional	33	40	33	
	zonal	10	15	1£	99%
Frankfurt	meridional	27	33	27	
	zonal	15	20	15	86%
Munchen	meridional	67	87	67	
	zonal	80	65	65	10%

during January and least during December, which is
consistent with the climatology of the region discussed in
chapter 3. The greatest difference of recurrence between
zonal and meridional regimes is also experienced during
January when alternating blocking episodes and vigorous
Atlantic depressions produce relatively stable climatic
modes.

In comparison with the entire record, both extreme
periods of meridional and zonal flow resulted in an
increase in temperature variability, although variability
of the meridional periods tended to be higher than that of
the zonal periods. With zonal flow, isotherms tend to be
east-west and cold air-masses are generally restricted to
higher latitudes, while warm air-masses are kept at lower
latitudes. Conversely, during meridional periods, isotherms
and isobars have a more north-south orientation. Both cold
and warm air can be advected into this area of central
Europe depending on the actual location of the large-scale
pressure features. This leads to high variability in
temperature, a fact which is extremely important for the
conduct of military operations.

5.3 The North Atlantic Oscillation

In the previous section, the NAO index was used as an
indicator of the zonality of windflow across the North
Atlantic. Periods of meridionality were found to be related

to increased variability in temperature and precipitation across East and West Germany. In Chapter 3 and in previous sections, it was demonstrated that meridional flows frequently resulted in cold air advection from the pole. This being the case, there may also be a direct relationship between circulation across the north Atlantic and temperature in central Europe. A similar relationship was found by Diaz and Quayle (1980) for the United States. During the first half of the century when the northern hemisphere was experiencing a period of zonal flow, the United States had substantially less variable temperature as compared to the meridional period which characterizes the flow since 1950. Meridional periods, therefore, can be associated with highly variable temperatures and zonal periods with less variability. If a similar relation exists for Germany, then there may be a way of determining the variability and probable state of the climatic elements just by looking at a simple index: the NAO. Such knowledge could be extremely beneficial for tactical operations in central Europe.

The NAO is a teleconnection pattern in the geopotential height field which is manifested in northern hemisphere. winter (Wallace and Gutzler, 1981). Teleconnections are significant simultaneous correlations in atmospheric variables at widely separated points on earth. The NAO was formally defined by Walker and Bliss (1932) as the tendency

for pressure to be low near Iceland in winter when it is
high near the Azores islands and southwest Europe. This
distribution is associated with high temperature in
northwest Europe and low temperature off the Labrador
coast. Mathematically, their version of the NAO is:

P (Vienna) + 0.7 P (Bermuda) - P (Ivigtut) - P
(Stykkisholm) + T (Bodo) + T (Stornoway) + 0.7 (arithmetic
mean of T (Hatteras) + T (Washington)) - 0.7 T (Godthaab)

Positive values of this index are associated with strong
zonal flow over the North Atlantic and adjacent areas, and
negative values are associated with meridional flow.

Because Stykkisholm, Iceland, and Ponta Delgada, Azores
Islands, lie near the mean centers of low and high
pressure, respectively, substantial departures from mean
sea level pressure at these two stations represent a
simpler, but effective index of major circulation changes
associated with the NAO preferred by modern investigators
(e.g., Lamb, 1972; Van Loon and Rogers, 1978; Rogers, 1984.
Moses et al., 1986). The NAO reflects the temporal
fluctuations of the zonal wind strength across the Atlantic
Ocean due to the pressure differences between the
subtropical anticyclone belt and the subpolar low (Rogers,
1984). It is this association of the NAO with the zonal

wind strength that plays an important role in climatic
variability of Western Europe.

The relationship between the NAO index and German
temperature was tested using linear regression techniques.
Results of monthly regressions for the full suite of
temperature stations is given in Table 5-7. Overall
correlations tended to be lowest in December, ranging from
a high of 0.53 (Stuttgart) to a low of 0.04 (Kiel). The
spatial distribution of December correlations (Fig. 5-3)
reflects a general increase from the southwest towards the
northeast. This pattern may be indicative of the
topographic control of the Alps on the surface air flow
across the continent. January coefficients, by far,
represent the strongest relationships. Values range from a
high of 0.74 (Stuttgart) to a low of 0.44 (Munchen). The
spatial pattern of these correlations is slightly different
than that of December. Correlations tend to increase from
west to east in a line running roughly parallel to the
northwest coast (Fig. 5-4). These high values can be
associated with the vigorous Atlantic depressions, coupled
with the high frequency of blocking patterns in January.
These factors result in high variability for temperature
during this month, with extreme contrasts between zonal and
meridional flow. February's correlations tend to lie in the
mid-range between December and January. The highest value
is 0.50 (Hamburg), and the lowest value is 0.36

Table 5-7

Linear regression of monthly NAO index and temperature. All values are significant at the 99% level.

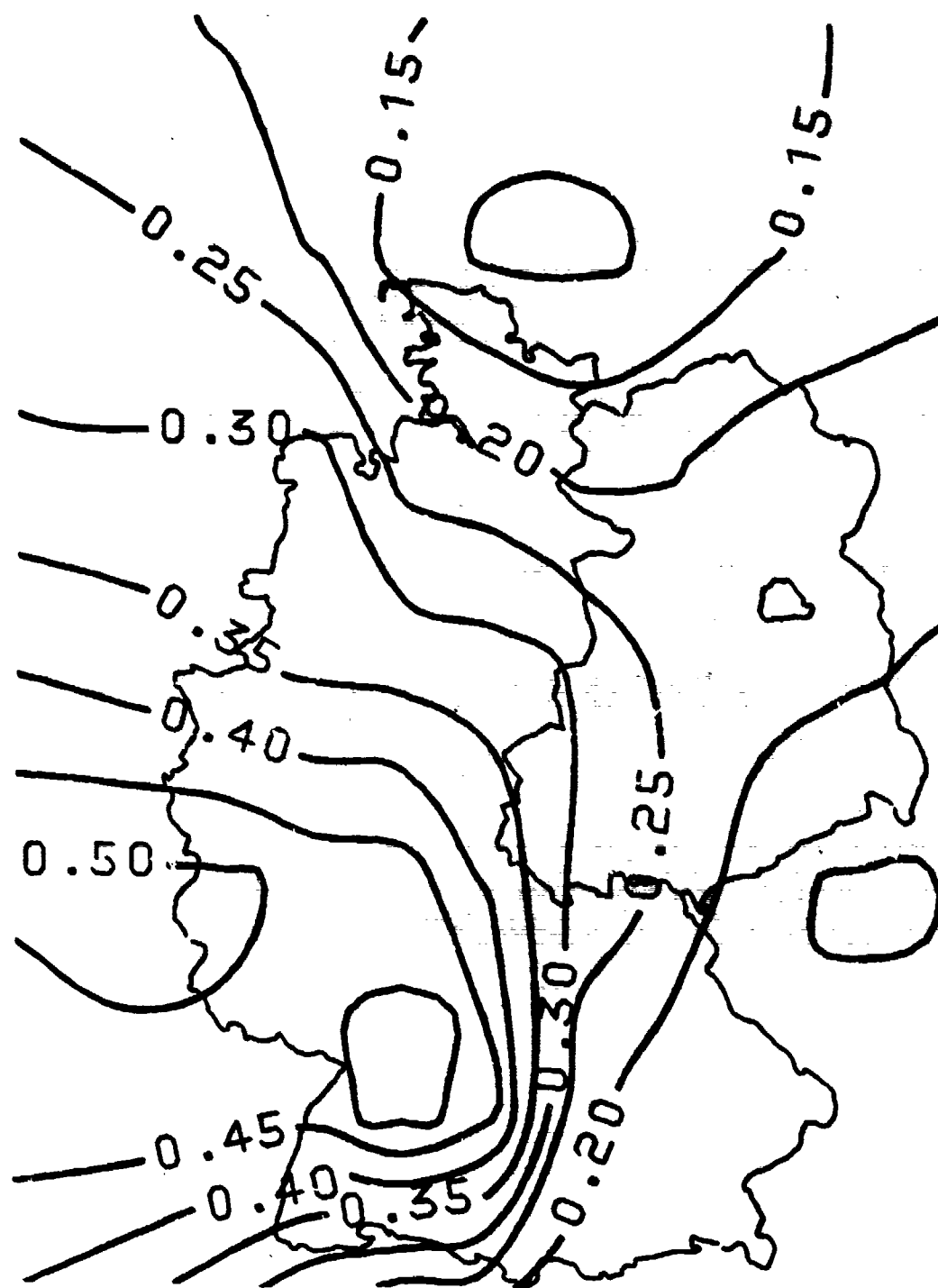| Station	December	January	February
Kiel	0.04	0.73	0.44
Hamburg	0.22	0.69	0.50
Emden	0.32	0.66	0.44
Hannover	0.32	0.67	0.47
Kassel	0.36	0.64	0.40
Frankfurt	0.48	0.71	0.36
Trier	0.52	0.67	0.36
Stuttgart	0.54	0.74	0.37
Munchen	0.14	0.44	0.40
Friedrichshaven	0.16	0.50	0.41
Hohenpeissenberg	0.18	0.45	0.36
Berlin	0.24	0.53	0.43
Potsdam	0.23	0.52	0.46
Erfurt	0.26	0.49	0.46
Dresden	0.13	0.52	0.39

Figure 5-3. Correlation coefficients of December temperature with monthly NAO index. All values significant at the 99% level.
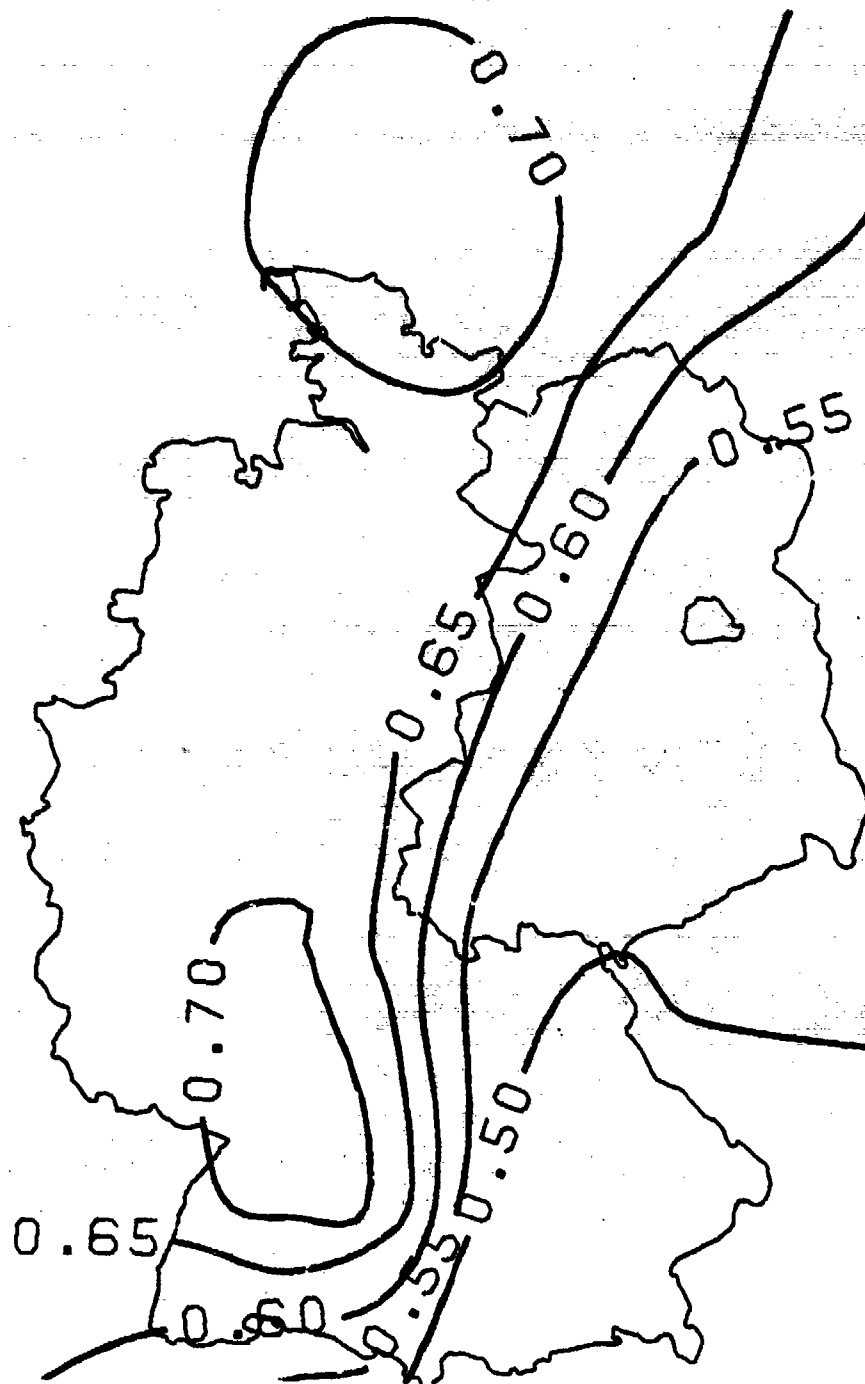
Figure 5-4. Correlation coefficients of January
temperatures with monthly NAO index. All values
are significant at the 99% level.

(Frankfurt). The spatial pattern of correlations in February (Fig. 5-5) tends to decrease from north to south. This may be attributed both to the high pressure which dominates this region as the snow and ice cover reaches its maximum extent, and to cold advection from the poles during periods of meridional flow. Regression of seasonal temperatures with seasonal NAO values (Table 5-8) reflects the average conditions which exists throughout the winter months. Values range from a high of 0.61 (Hamburg), to a low of 0.36 (Munchen). The spatial pattern seems to indicate a decreasing relationship from the northwest to the southeast (Fig. 5-6). This suggests that topography plays a major role in reducing the effects of upper atmospheric flows on the climatic elements on the ground.

The problem of low correlation values needs to be addressed on the grounds of both dynamical and methodological arguments. One would assume that the circulation across the Atlantic should have some relationship to the temperature in central Europe. Although this relationship can be found in the temperature/NAO index correlation coefficients, it is not as strong as might be expected. Methodological constraints, revolving around the amount of unexplained variance, can suggest reasons for some of these low values. First, linear regression analysis is a technique which attempts to find a relationship by fitting the two variables to a straight

Figure 5-5. Correlation coefficients of February
temperatures with monthly NAO index. All values
are significant at the 99 % level.

Table 5-8

Linear regression comparing winter season NAO index and temperature. All values are significant at the 95% level.

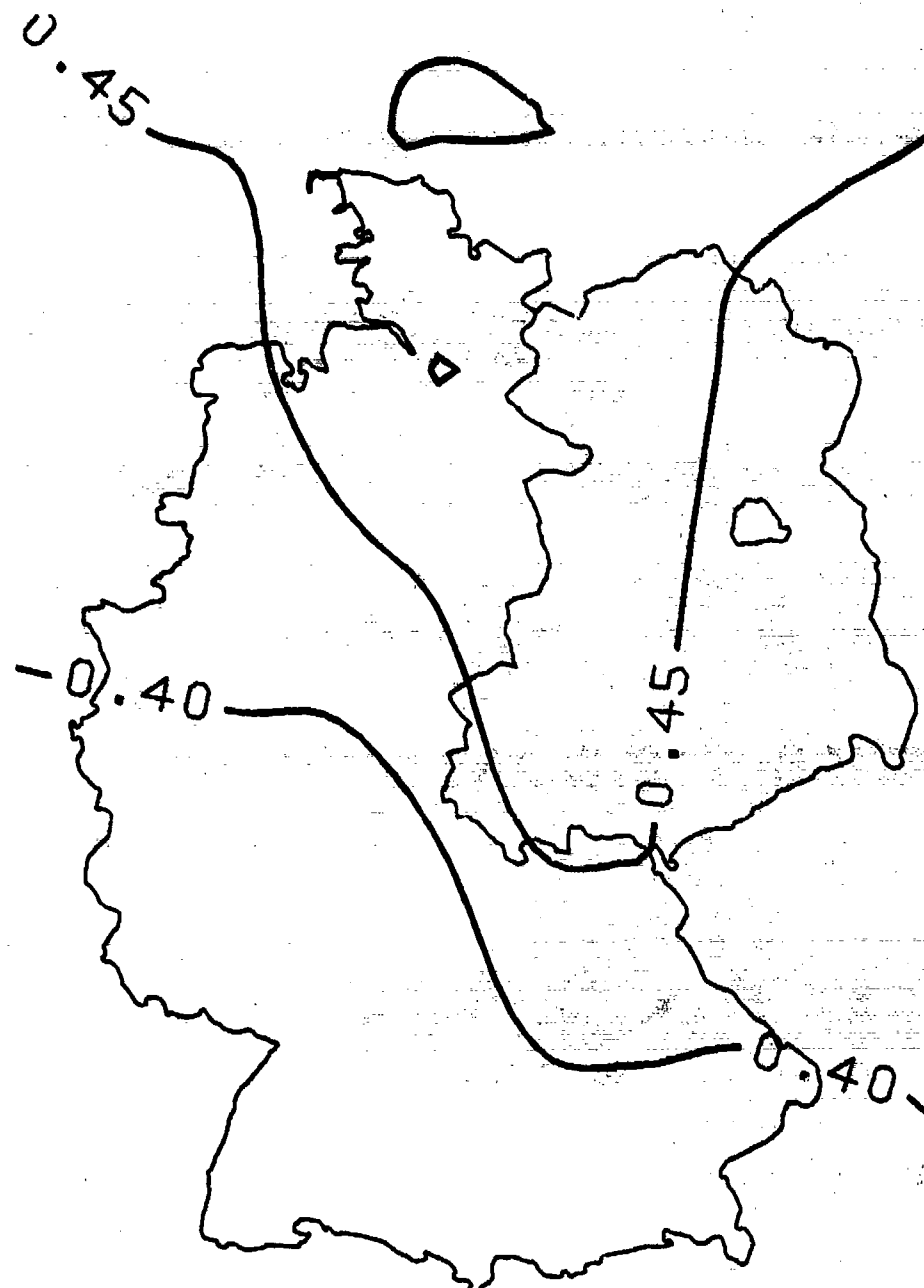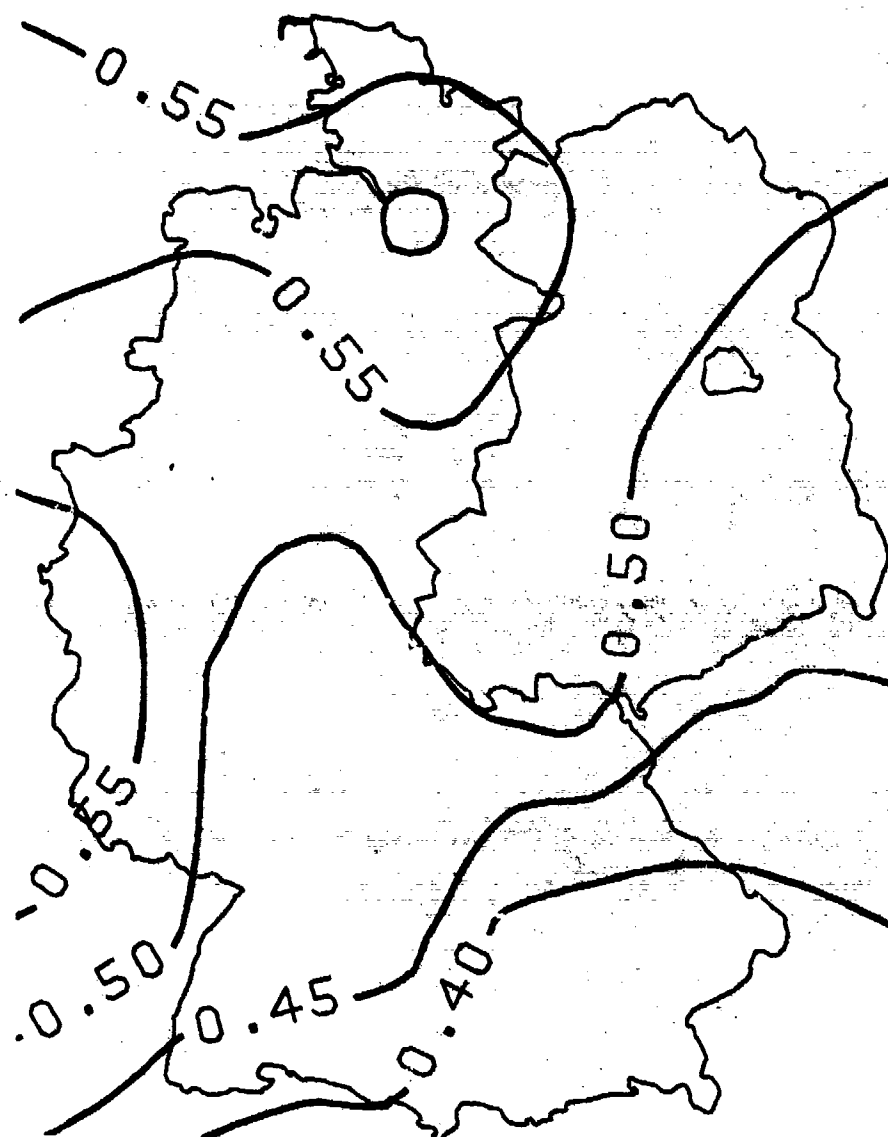| Station	r	r^2
Kiel	0.48	0.23
Hamburg	0.61	0.38
Emden	0.56	0.31
Hannover	0.57	0.33
Kassel	0.45	0.21
Frankfurt	0.47	0.22
Trier	0.59	0.35
Stuttgart	0.49	0.24
Munchen	0.36	0.13
Friedrichshaven	0.35	0.12
Hohenpeissenberg	0.38	0.15
Berlin	0.50	0.25
Potsdam	0.50	0.25
Erfurt	0.52	0.27
Dresden	0.44	1.93

Figure 5-6. Correlation coefficients of seasonal
temperature with seasonal NAO index. All
values are significant at the 99 % level.

line. If the relationship is not linear, then significant amounts of unexplained variance can be introduced into the correlations. This relationship can be easily tested by producing a scatter plot of the NAO versus temperature or precipitation. If there is a nonlinear relationship then it should show up on the graph. When such a scatter plot was produced, there was no readily apparent pattern or relationship, although no statistical tests were applied to confirm this qualitative assessment. A second methodological problem which may account for unexplained variance is the number of variables used in the regression. If more large-scale environmental variables are added (e.g. elevation, an index of the strength of the Siberian high, stability, extent of snow cover, ice extent, or sea surface temperatures in the North Atlantic) then presumably more of the variance could be explained. However, perhaps the most powerful argument concerning the unexplained variance lies in the limitations of one of the variables: the NAO index, itself. Although the NAO index is good for describing relative strength and zonality of the flow across the North Atlantic, it cannot indicate the precise location of storm tracks or jet streams over central Europe. If the jet stream is displaced a mere 100 km, then drastically different surface climatic effects may be felt on a regional scale. Unlike North America which has a mountain range running north to south, Europe's mountains tend to

run east to west and do not anchor the upper level winds
into quasi-stable climatic patterns. Within general zonal
or meridional regimes, longwaves are relatively free to
meander across central and northern Europe, steering
smaller systems as they go. Thus, the NAO index cannot be
used to indicate these finer fluctuations in the jet
stream. In light of the above problems, the low
correlations between climate and the NAO are not
surprising. However, the temperature-NAO relationship does
suggest that general zonal or meridional airflow
trajectories influence the climate of central Europe.

5.4   Recapitulation

Although the temperature series of East and West
Germany are homogeneous, they can best be characterized by
a general lack of persistence throughout the entire record.
In addition, very large intraseasonal and interannual
variability reflect an alternation between mild conditions
and prolonged periods of cold which is common for this
region.

Extreme periods of cold can be associated with synoptic
scale weather patterns which advect cold air from the north
or northeast. The recurrence of these synoptic weather
patterns and cold periods is related to the relative
zonality of upper air flow across the North Atlant'
During meridional flows, there is increased temperature

variability and recurrence of extremely low temperatures. On the other hand, zonal flows result in lower temperature variability and more persistent, milder conditions. The NAO index can be used as a measure of the zonality of winds across the North Atlantic and is used here to test the relationship between meridional flows and low temperatures. Correlation coefficients indicate that there is a positive relationship between the two and that as much as 30-40% of the temperature variance during certain winter months over the past 100 years can be explained using this simple index.

In this chapter it was found that mean monthly temperatures below 0° C are, in fact, common for this region and are related to airflow trajectories across central Europe. The winters of 1940 to 1942 during the height of World War II are indicative of the substantial impact which such extreme cold periods can have on the outcome of military operations. If the Army could only predict with some degree of accuracy the onset of such cold periods, then it would be better able to plan for the complexities of modern warfare. Although various relationships were found during the course of this study between air flows and periods of extreme cold, the technique applied here is far from an operational predictor of adverse conditions. This study represents a starting point from which to launch future research into the

possible impact of climatic elements on tactical operations. A commander must obtain information of _all_ the possible uncertainties of modern warfare if he is to make a sound decision in the face of a hostile enemy. Climate and weather is a critical factor in tactical proficiency which must not be overlooked. Only through a thorough knowledge of the factors influencing the climate of a region can military leaders take full advantage of the opportunities provided and minimize the adverse impacts of climate and weather.

Chapter 6

CONCLUSION

6.1 Summary

In order to fight efiectively, military commanders must
(1) understand the seasonal weather patterns that influen)e
his area of operation; (2) know how to acquire this
information; and (3) know how to use this information to
exploit the opportunities and minimise the negative impacts
provided by weather.

The defense of NATO is one of the principal missions of
the Army. Germany represents the first-line defense in that
overall mission. It is imperative to apply knowledge of
climatology to this region in order to fully understand the
possible adverse impacts which may result during extremely
cold periods.

Soldiers respond to their thermal environment in a
complicated manner. Physiological and behavioral responses
occur when the difference between ambient temperature and an
individual's average body temperature exceeds a threshold
value. Physiological responses (thermoregulation) depend on
energy stores, age, sex, build, race, and various inhibitors.
Body extremities are particularly vulnerable to temperature
imbalances, resulting in a decrease in performance as
temperatures deviate from normal. Behavioral responses
include migration, acclimation, and clothing. Tactical

military operations are conducted in extreme environments, for extended periods, and frequently with inadequate logistical support. Extreme variations in temperature, therefore, tend to impact adversely on operations as resistance to infection and performance levels decline.

German winter temperature results from the interaction of the Icelandic low, the Azores high, and, infrequently, the Siberian high. Maritime effects decrease from the north to the southeast. Regional topography channels the air in certain areas and aids in producing a distinct regional pattern of weather and climate. Sea ice extent and snow cover contribute to the predominant high pressure of mid-winter. German winter temperature can be characterized by large intraseasonal and interannual variability resulting in a general lack of persistence of the climatic elements. The most pronounced variability and cold occurs during periods of meridional flow. The North Atlantic Oscillation can be used as a measure of flow across the North Atlantic to explain between 30-40% of the temperature variation during certain months in the winter season for the past 100 years. This study presents preliminary techniques which can be used to assess the effects of weather and climate on operations as dictated by FM 100-5 (1986).

6.2 Future Climate and its Impact on Military Planning

The need to understand and plan for the effective use of climate has serious implications for long-term military strategy. As indicated in chapter 1, temperature impacts on equipment is minimized through the design and aquisition process. However, this is based on an efficiently operating acquisition system and, more importantly, constant climate. The acquisition of a new item of equipment, under the current bureaucracy and "red tape," can be a painstaking and drawn out affair. From the time of conceptualization to the time of actual fielding, it is not unusual for the process to span a period of a decade or more. If we assume that the operational usefulness of that equipment is 25 years, then it may be that the entire planet will be well within the period of predicted climate change due to the enhanced greenhouse effect caused by carbon dioxide and other trace gases. Under such conditions of rapid climatic change, the current acqusition system is not sufficient to guard against the possible impacts of temperature. In addition, the impacts of temperature on individuals may also be substatially affected. The question then becomes one of speculation. Do we use the current level of temperature and precipitation variability to define our design parameters, or do we use what we think our level of variability will be 30-50 years from now? Whichever the choice, the implications for future operational performance are serious.

Much has been written recently concerning the possible impact of CO_2-warming on climate (see DOE/ER, 1985,1986). For the first time in our history, we have the capability to predict a dramatic climate change and not just react to it. A number of computer models have been used to simulate this predicted change with varying results (DOE/ER, 1985, Table 4.4 and Figures 4.20 through 4.38). A synthesis of the model results leads to the following consensus (Luther, 1985).

(1) All models predict tropospheric warming and stratospheric cooling.

(2) Global evaporation will increase due to the increase in water vapor capacity as global temperatures rise.

(3) Both warming and precipitation are regional with some areas cooler/wetter and some areas warmer/drier.

(4) All models showed a decrease in sea ice and seasonal snow cover.

(5) Areas most effected by warming were located at the higher latitudes, possibly reflecting changes in the ice-albedo feedback.

(6) Sea levels will most certainly rise due to the melting of the cryosphere and the thermal expansion of the ocean.

(7) The mediating effect of the ocean will slow the onset of the warming and prolong the effect as well.

Although no observed evidence has been provided which relates
the increase in global warming to increased variability of
temperature and precipitation, theoretical-dynamical
arguments have been used to argue the case. If the polar
regions warm at the same time the tropics cool, then the
equator to pole temperature gradient is reduced. By
decreasing this gradient, the strength of the jet streams and
the associated upper tropospheric waves are also reduced.
Since zonal flows are associated with strong upper level
westerlies, and meridional ones with weak motion, by
decreasing the temperature gradient a condition is created
which favors meridional flows. More meridional westerlies, as
demonstrated throughout this thesis, are associated with
increased variability in temperature and more frequent
outbreaks of cold air over Germany.

The Army spends large amounts of time and money for
contingency planning and acquisition of new weapon systems.
Because this process is slow, as well as expensive, it is
vital that time is not wasted on planning which will not be
able to withstand the vigor of future climates. From casualty
replacement tables, to preposition of materials configured to
unit sets (POMCUS), to readiness conditions, the worst-case
predictions of temperature extremes and variability should
therefore be used for future planning.

5.3 Recommendations

Although the Army has long recognized the significant impact of weather and climate on both friendly and enemy capabilities it has given inadequate treatment to this subject. Current IPB procedures stress the importance of graphic portrayal of information as the best means of providing information to the commander. In keeping with this concept, historical weather analysis should include a time series plot of the various climatic elements as well as maps showing the spatial variation of these elements on various scales. This graphic portrayal should replace or at least supplement the current narrative form, thereby allowing the commander to efficiently draw his own conclusions as to the nature of the climatic elements in his area of operation.

In addition, the Army needs to establish a repository for climatic data pertaining to decreased human performance levels. As the role of climate in tactical operations becomes increasingly apparent, there will be a need to assess the impact of current and future climates on operational proficiency. In order to do so requires a substantial data base to distinguish between the various causal factors affecting performance. This data base should be established now so that full advatage of all the opportunities provided by weather and climate can be taken.

Climate considerations, in general, must be brought up to date in the IPB and planning processes. Current procedures

are not on line with either current doctrine nor the technology available in the scientific community. The role of climate and weather has been much too important in the outcome of past military engagements for the Army not to pay attention. Climate and weather are not conditions which effect both enemy and friendly forces equally. The leader who understands the effects of weather and climate, and who is best prepared to take advantage of the opportunities which result from those effects, has added another combat multiplier in his arsenal of weapons. This multiplier, as history has taught us, may be most critical.

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